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Project Completion
Report No.
RF 760851 - 710797

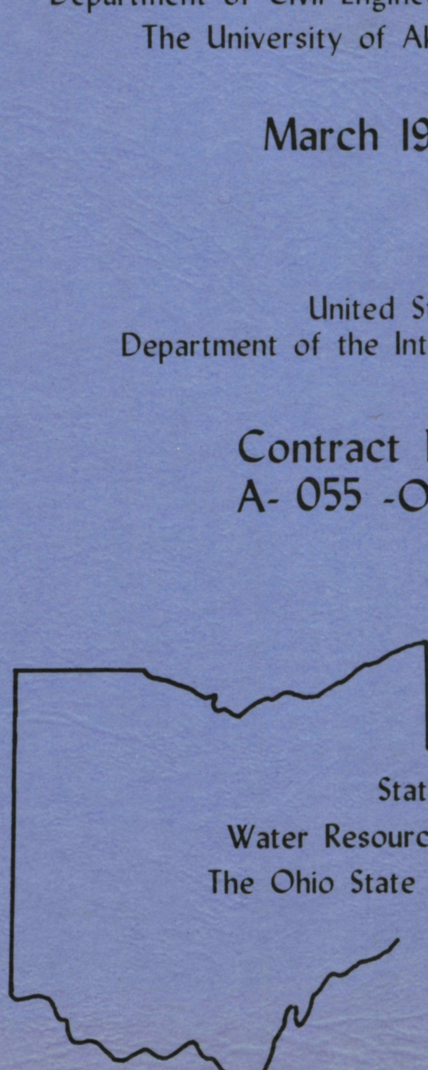
Development of a Mathematical Model for Urban Runoff Quantity and Quality

S. Sarikelle
Department of Civil Engineering
The University of Akron

March 1980

United States
Department of the Interior

Contract No.
A- 055 -Ohio



State of Ohio
Water Resources Center
The Ohio State University

Project Completion Report

DEVELOPMENT OF A MATHEMATICAL MODEL FOR URBAN RUNOFF QUANTITY AND QUALITY

By

S. Sarikelle
Department of Civil Engineering
The University of Akron
Akron, Ohio 44325

March 1980

Contract No. A-055-OHIO

Water Resources Center
The Ohio State University
Columbus, Ohio 43210

DISCLAIMER

The opinions, findings and conclusions expressed in this report are those of the author and not necessarily those of the Office of Water Resources Research, U.S. Department of the Interior or the State of Ohio Water Resources Center.

ABSTRACT

An urban runoff model has been developed for the simulation of stormwater quantity and quality. The model consists of a quantity submodel and a quality submodel. The quantity submodel utilizes the Linearized Subhydrographs Method to simulate runoff hydrographs for recorded and synthetic storm events. The method is based on a simplified concept where hydrographs are generated for each sub-catchment in accordance with the duration of the rain and the time concentration. The quality submodel consists of determination of stormwater pollution levels. In the simulation of pollutant removal process, a relationship signifying the effect of incremental runoff volume and the effect of the depth of flow upon pollutant removal efficiency is incorporated.

Accuracy of the model is then tested by applying the model to urban watersheds with recorded rainfall, runoff and quality data. The model may be used as an alternative to the more comprehensive and complex models in the planning and analysis of stormwater systems.

Keywords: Urban runoff, Hydrographs, Pollutants, Water pollution, Drainage, Computer models, Flood routing, Sewers, Urbanization, Rainfall-runoff relationships, Storms.

ACKNOWLEDGMENTS

This report summarizes the results of a study sponsored by The Office of Water Resources Research, U.S. Department of the Interior and administered under Project No. A-055-OHIO by the Water Resources Center, Ohio State University.

The study was made possible by the dedication and ingenuity of Mr. Yu-Tang Chuang, Research Assistant in the Department of Civil Engineering.

Mr. Jong-Son Chien, Chien Associates, Houston, Texas and Dr. Gus Mavrigian, Professor of Mathematics, Youngstown State University, gave valuable suggestions during the course of the study. Mr. Gary L. French, former Research Assistant, now with the Colonial Pipeline Co., Atlanta, Georgia, helped with the programming and modeling.

Thanks are due to Mr. Gayle Seymour and personnel of the computer center for their help and support. Finally, special thanks are due to the many undergraduate and graduate assistants who helped in the data preparation and development of the model and to Mrs. Dorothy Guilliams for typing the manuscript.

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CHAPTER I

INTRODUCTION

Urban stormwater management has drawn much attention in recent years due to problems associated with quality of storm runoff and its detrimental effects on receiving waters. Although the problem dealing with quantity of urban runoff can be handled directly, the problems resulting from quality aspects are more complex and difficult to assess especially when coupled with the runoff process.

Studies have shown that pollution carried by stormwater discharging untreated and highly polluted street washings into receiving waters exceed those discharges from secondary municipal treatment plant effluents (13, 20, 44). Indeed, in many cases, the quality of receiving waters is more likely to be governed by waste produced in urban areas which is flushed away by rainfall.

Recognizing this problem, the Federal Water Pollution Control Act Amendments of 1972, requires each state to prepare a report identifying the nature and extent of nonpoint sources of pollution and requires the development of water quality and quantity management strategies to deal with the effects of combined and separate sewer overflows on the quality of receiving waters.

The nonpoint sources of pollution are difficult to identify since the discharge of such pollution can be found in various forms and from any sources. The difficulty stems from the fact that pollution originates from areas with varying geomorphological, climatological and physical characteristics. Basically the nonpoint discharges can be categorized as being generated from agricultural lands, forests, mining operations and from urban areas. The urban runoff, including storm sewer discharges and combined sewer overflows, is a major contribution of the nonpoint sources of pollution.

Due to the very complex nature of the urban rainfall-runoff-quality process, it is recognized that the utilization of mathematical models provide an efficient approach for the investigation of the various aspects in urban drainage systems. Over the years, various methods of analysis have been developed for this purpose. Documented analytical methods in urban hydrology range from the very simple Rational Formula to the detailed U.S. EPA Stormwater Management Model (6,16). However, few of these mathematical models have incorporated the qualitative aspect of the urban runoff phenomena in an efficient and simplified manner. The basic mechanism of the pollutant washout by runoff water needs further attention in a more logical manner using simplified approaches.

The study presented herein details the effort made in the development of a quantity and quality model with simple input requirements to be used in conjunction with studies related to urban wastewater management strategies. The model entitled MLSURM, an acronym for a Modified Linearized Subhydrographs Urban Runoff Model, is capable of simulating both the quantity and quality of the urban stormwater for either separate or combined sewer systems. The sensitivity of quantity and quality parameters incorporated in the model is analyzed to demonstrate the model's performance. The model is then tested by applying it to various watersheds with recorded rainfall events and measured runoff data.

CHAPTER II

LITERATURE REVIEW

Since the enactment of the Water Pollution Control Act Amendments of 1972 (PL 92-500), planning of water quality policies and pollution control strategies in urban areas have received considerable attention. As part of these activities various approaches have been suggested in the analysis and determination of quantity and quality aspects of stormwater (17, 20, 23, 25, 37). There are several methods that are used in the determination of nonpoint source pollutants from urban areas (12, 17, 18, 30, 36). Recently, greater emphasis has been placed on the development and the utilization of simulation models (2, 4, 7, 8, 14, 15, 19). Such models are economical to use because only limited data is required to evaluate various water pollution abatement alternatives for an urban watershed.

Although details of existing mathematical models can be found in literature, the following is a brief review of some of the significant models that have been developed for simulating urban runoff quantity and quality.

Review of Models

Colston (13) in his study on a 1.67 square mile urban watershed in Durham, North Carolina, sampled various pollutants during runoff events in an attempt to create a prediction equation relating pollutant flux to runoff events. Regression analysis of the sampled data yields a general equation of the form:

$$P = \hat{K}Q^a t^b \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (1)$$

where

P = pollutant flux

$\hat{K}$ = constant related to the particular pollutant

Q = discharge

t = time from the beginning of the storm

a and b = constants determined from the regression analysis for the particular pollutant

This equation could be applied to model various pollutant concentrations but requires substantial study of the drainage basin involved. Because of the regression analysis, the method predicts the pollutant concentrations but it does not attempt to model the mechanics of the pollutant removal process from a drainage area.

A comprehensive sampling program for stormwater in several Houston area watersheds was reported by Bedient (2). Regression analysis of the sample data yielded linear relationships between pollutant mass loading rates and total storm runoff volume. A quality simulation model HLOAD was developed to predict pollutant mass flow rates by applying the load-runoff relationshps to runoff flows. The drawback of the model is that a runoff data sampling program is essential in order to establish the load-runoff relationships for a given watershed.

Brandstetter (16) reviewed 18 mathematical models and presented their quantitative and qualitative features. The majority of the models reviewed, however, did not consider water quality features:

1. British Road Research Laboratory Model
2. Chicago Flow Simulation Program
3. Chicago Hydrograph Method
4. Colorado State University Urban Runoff Modeling
5. Dorsch Consult Hydrograph-Volume Model
6. Massachusetts Institute of Technology Urban Watershed Model
7. Minneapolis-Saint Paul Urban Runoff Model
8. Sogreah Looped Sewer Model
9. University of Cincinnati Urban Runoff Model
10. University of Illinois Storm Sewer System Simulation Model
11. University of Massachusetts Combined Sewer Control Simulation Model
12. Wilsey and Ham Urban Watershed System
13. Seattle Computer Augmented Treatment and Disposal System

This model can provide real time control of untreated overflows but cannot simulate runoff quantity or quality for new systems.

The following models do simulate qualitative aspects of urban runoff:

14. Battelle Urban Wastewater Management Model

This model was developed to simulate runoff quantity and quality through major sewer system components. Storm water quality is modeled using regression equations which relate the pollution level of each water quality constituent to the storm runoff rate, cumulative runoff volume during the storm, and initial conditions. Because of the regression procedure used, the stormwater quality variation due to changes of land use pattern cannot be simulated.

15. Corps of Engineers STORM Model

The primary purpose of this model is to evaluate storm water, storage and treatment capacity to reduce untreated overflows. The model can continuously simulate hourly stormwater quantity and quality for one catchment up to a period of several years. However, the model cannot route the surface runoff flow and quality through a sewer or channel network. This model is most suitable for planning purposes such as the assessment of future treatment or storage requirements of stormwater under different land use policy. The model calculates runoff quality by nonlinear functions considering rate of accumulation, land use, street sweeping practices, percent pollutants in the debris and runoff rates.

16. Environmental Protection Agency Storm Water Management Model

The U.S. EPA Storm Water Management Model (SWMM) has been recognized as one of the most comprehensive mathematical models for the simulation of runoff quantity and quality of urban sewer systems. Surface runoff from pervious and impervious areas is computed separately and routed to inlets through street gutter or pipe. Storm water quality is computed by a nonlinear function based on land uses, pollutant accumulation period, street cleaning and runoff rate. The pollutant removal from catchbasin is also calculated. The model then routes the combined storm runoff and sewage flows through converging network system to produce an outfall hydrograph and pollutograph. If the outfall is a treatment plant, the model simulates geometric storage treatment facilities and calculates the cost of the design. If the outfall is connected to a large body of water, the model then simulates the impacts of the receiving water due to the loading of sewer system hydrographs and pollutographs. The model has been tested on various urban catchments. However, the simulation of runoff quantity has been more successful than the runoff quality prediction. Continuous improvements of the model have added snowmelt modeling capability and soil erosion routine to the model.

17. Hydrocomp Simulation Program

This model is capable of continuous simulation of runoff flows and pollutant concentration from several basins and flow routing through sewer or open channel networks. The calculation of the runoff quality is similar to the formulations used in the E.P.A. SWMM.

18. Water Resources Engineers Storm Water Management Model

This model is a modified version of E.P.A.SWMM. However, utilization of the dynamic wave equation for the flow routing in the sewers enables the model to simulate backwater, flow reversal and upstream and downstream flow controls. Water quality modeling is based on SWMM's approach.

The models noted above do not attempt to incorporate the basic mechanism in pollutional loading removal by runoff-water. Some of the models utilize a regression analysis based on historical data to estimate runoff quality from a given catchment, thus limiting the applicability to other catchments. Other models such as Environmental Protection Agency's SWMM considers the rate of runoff as a part of the physical condition but fails to take into account the force responsible for transporting the material making up the pollutional loads.

Review of Mathematical Relationships

Over the years, a number of studies dealing with basic relationships have been developed and used in predicting the urban runoff pollutants.

Metcalf and Eddy, Inc. developed an equation in the following form which is utilized in the SWMM model (8, 9, 10, 11) to compute the amount of pollutant washed off the watershed during a storm:

$$P = P_o e^{-\overline{K}Rt} \qquad (2)$$

where P_o = amount of pollutant on the surface before the storm

P = amount of pollutant remaining on the surface after time, t

R = rate of surface runoff

$\overline{K}$ = rate constant of surface pollutant washout by runoff water. $\overline{K}$ = 4.6 by assuming that a uniform rainfall of 1/2 inch per hour would wash away 90 per cent of the pollutant in one hour.

Thus, the rate of removal of pollutant from the watershed is:

$$M = P(t) \cdot (1 - e^{-\overline{K}R\Delta t})/\Delta t. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

where

M = rate of removal of pollutant during time interval Δt

Δt = time interval

P(t) = amount of pollutant on the surface at time, t

R = rate of surface runoff

$\overline{K}$ = rate constant

In applying equations (2) and (3), stepwise computation is necessary for the entire storm runoff period with varying runoff intensities. In lieu of these stepwise computations, Chien (38) formulated equations as follows:

$$P = P_o e^{-\overline{K}V_t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

and

$$M = P_o(e^{-(\overline{K}V_t)} - e^{-(\overline{K}V_{t+\Delta t})})/\Delta t \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

where:

P_o = amount of pollutant on the surface before the storm

M = rate of pollutant washout during time interval Δt

V_t = cumulative runoff water volume, at time t

$V_{t+\Delta t}$ = cumulative runoff water volume, at time $t+\Delta t$

Sartor (12) developed an equation, based on experimental data from a rain simulator, in the following form:

$$N_c = N_o(1 - e^{-\overline{K}rt}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

where:

N_c = amount of material for a given particle size which has been removed during time interval t by a rainfall intensity r

N_o = initial loading intensity of that material for a given particle size which could be washed from the street by rain of intensity r, and

$\overline{K}$ = a proportionality constant dependent on street surface characteristics.

Thus the state of the art of simulating the urban runoff pollutant removal process relies basically upon the exponential relationship. Also, it is noted that most of the models developed to date are complicated in model structure and require extensive input data. Therefore, there is a need to develop a runoff quantity and quality simulation model which utilizes simplified input data and yields results which are comparable to those obtained by the more comprehensive and complex models.

CHAPTER III

DEVELOPMENT OF THE MODEL

The present chapter describes the procedures and methodology used in the development of (a) the quantity model and (b) the quality model. The quantity model consists of simulation of storm water hydrograph for a drainage basin due to rainfall events. The quality model consists of determination of pollution level of storm water for quality constituents such as suspended solids (SS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), coliforms, nitrogen, and phosphorus.

Quantity Model

The quantity model basically represents the simulation of runoff flow for a given rainfall event. The method is based on a simplified concept (5, 24, 40) where hydrographs are generated for each subarea in accordance with the duration of rain and the time of concentration for the area. Three cases of linearized subhydrographs are assumed for each subcatchment.

In case I, $t_r = t_c$; that is, storm duration equals the time of concentration of the subbasin. As shown in Figure 1, the peak runoff occurs when the total flow from the subbasin contributes to the inlet. The peak runoff rate is defined by:

$$q_p = C\ i\ A \qquad (7)$$

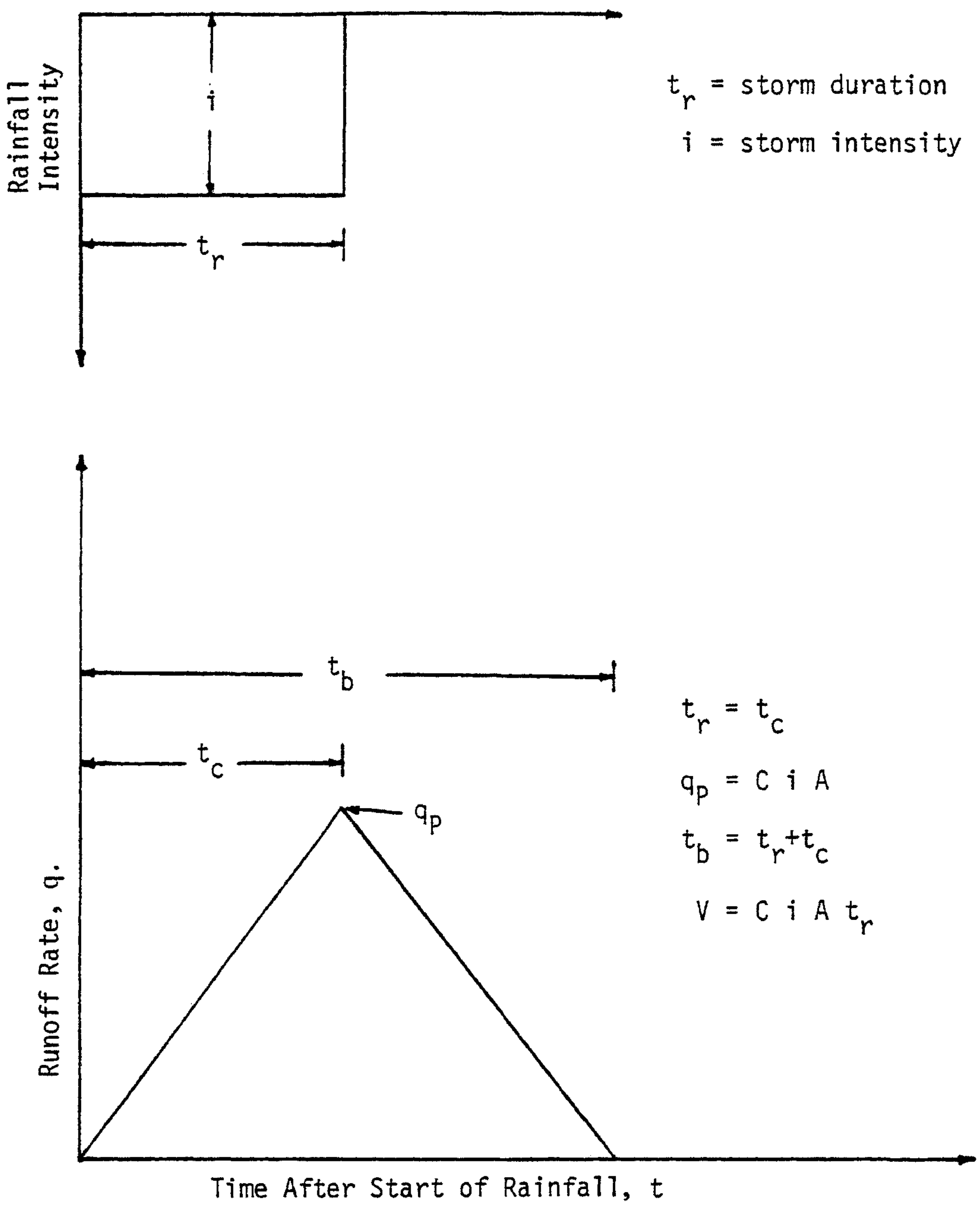


Figure 1 Case I Linearized Subhydrograph (5)

where:

q_p = peak runoff rate (ft^3/sec)

C = runoff coefficient

i = intensity of rainfall (inches/hour)

A = area of the subbasin (acres)

The runoff rate of the rising and receding limbs are determined by assuming a linear relationship between the runoff and time. For $t \leq t_r$, the runoff rate q_t at time t is given by:

$$q_t = C\ i\ A\ \frac{t}{t_c} \qquad (8)$$

For $t > t_r$, the runoff rate is calculated by:

$$q_t = C\ i\ A\ \left(\frac{t_r + t_c - t}{t_c}\right) \qquad (9)$$

The time base of the subhydrograph, t_b, the time period from the beginning rainfall to the time when the runoff rate subsides and becomes zero, is computed by:

$$t_b = t_r + t_c = 2t_r \qquad (10)$$

The volume of runoff V resulting from the storm is then calculated by:

$$V = C\ i\ A\ t_r \qquad (11)$$

In case II, the storm duration is assumed to be greater than the time of concentration for the subbasin, that is $t_r > t_c$. Thus, after a time period equal to the time of concentration, the peak runoff rate is reached and remains constant until the rainfall stops. Then, the runoff recedes to zero in a time period equal to t_c. Therefore, the runoff rate of the subhydrograph is given by:

$$\text{For } t < t_c,\ q_t = C\ i\ A\ \frac{t}{t_c} \quad . . . . \quad (12)$$

$$\text{For } t_c \leq t \leq t_r,\ q_t = C\ i\ A = q_p \quad . . . . . \quad (13)$$

$$\text{For } t > t_r,\ q_t = C\ i\ A\ \left(\frac{t_r + t_c - t}{t_c}\right) \quad . . . . \quad (14)$$

The time base of the subhydrograph is given by:

$$t_b = t_r + t_c \quad . . . . \quad (15)$$

The runoff volume V is then computed by:

$$V = C\ i\ A\ t_r \quad . . . . \quad (16)$$

A schematic representation of this case is shown in Figure 2.

In Case III, $t_r < t_c$, that is, the time of concentration for the subbasin is greater than the storm duration. Thus, the equilibrium runoff rate is not reached when the storm ceases. In the original version of the linearized subhydrograph concept (5, 24, 40), a triangular subhydrograph as shown in Figure 3 was proposed. The adjusted peak runoff rate was given by:

$$q_p = C\ i\ A\ \left(\frac{2t_r}{t_r + t_c}\right) \quad . . . . \quad (17)$$

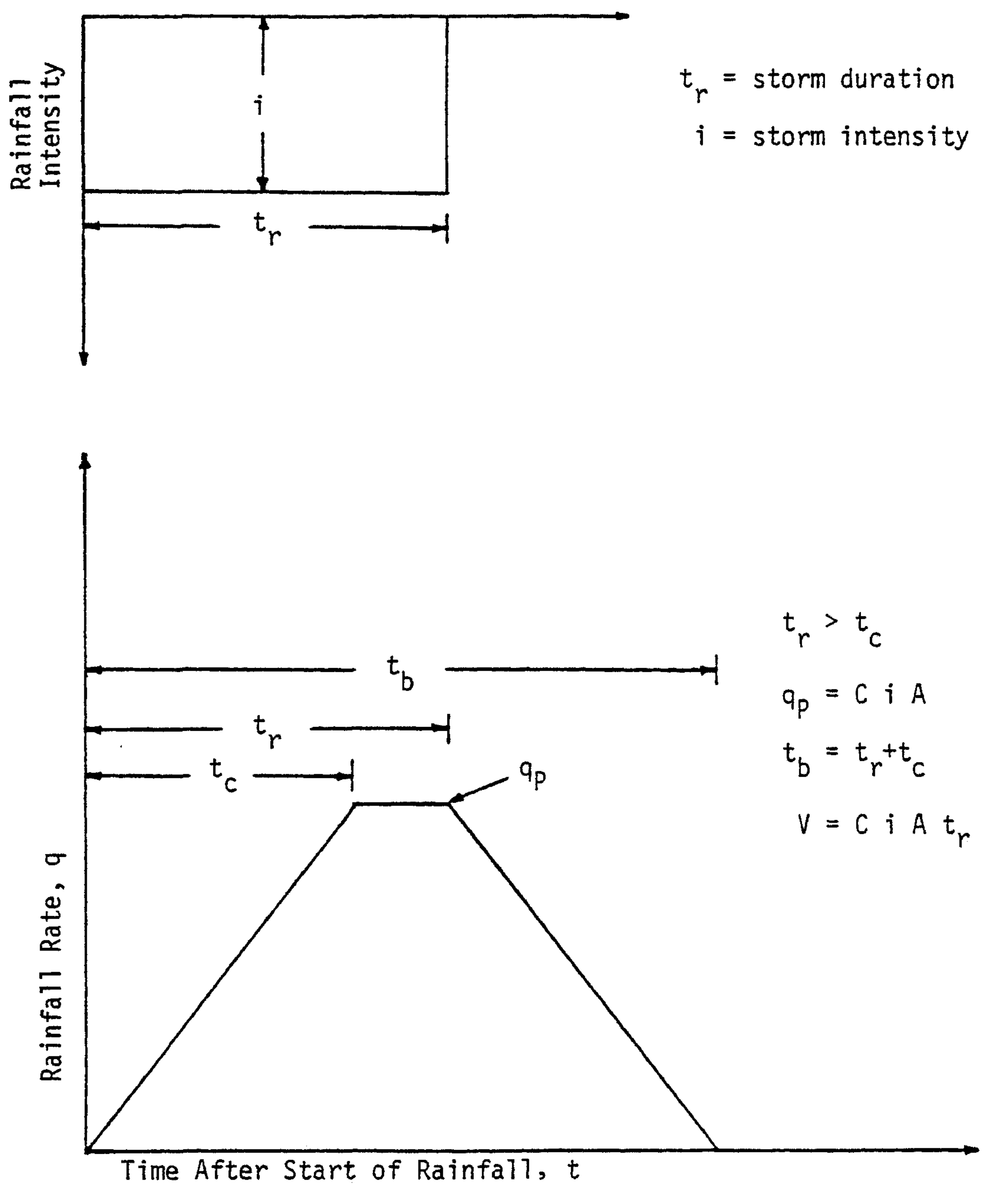


Figure 2 Case II Linearized Subhydrograph (5)

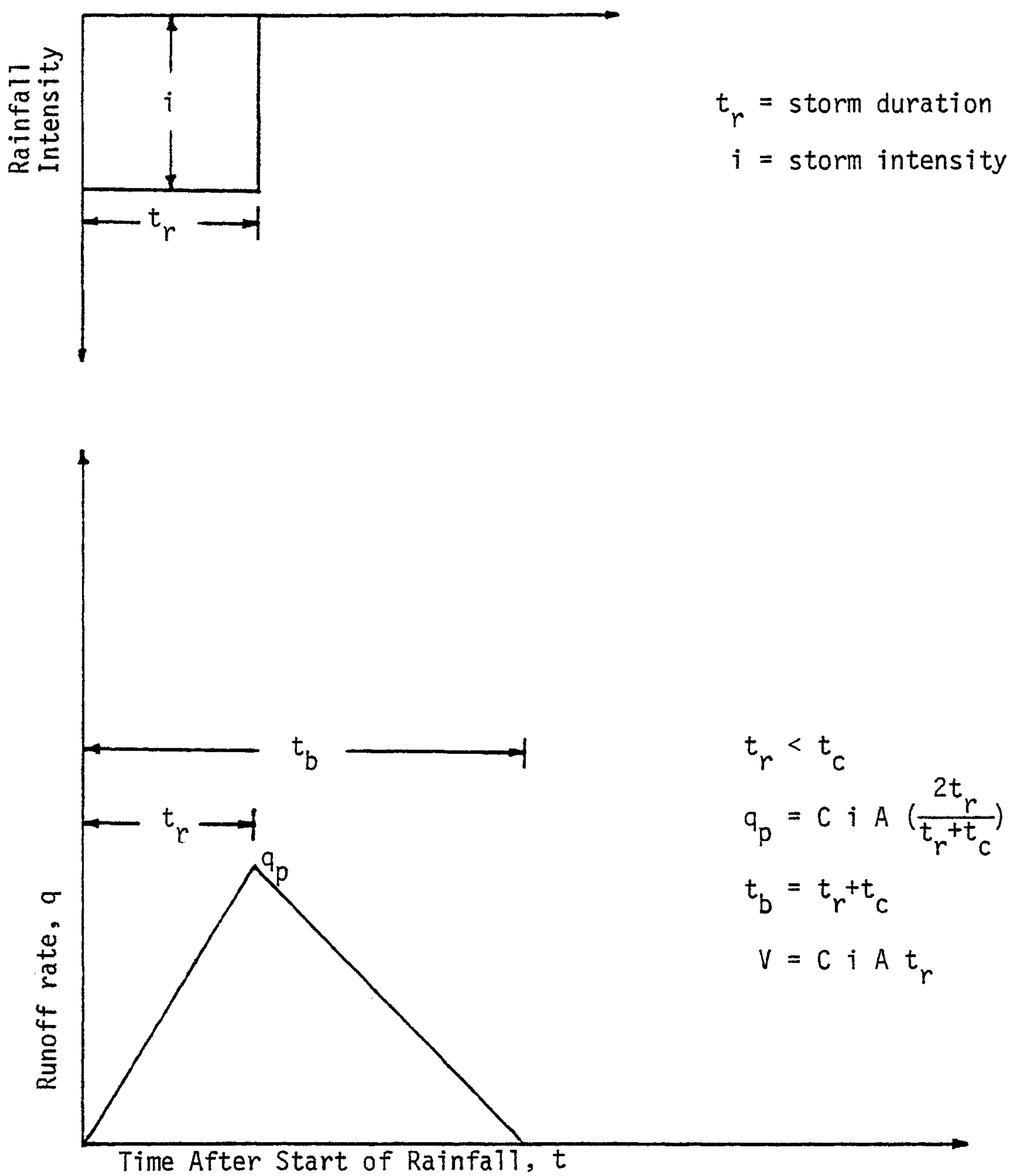


Figure 3 Case III Original Linearized Subhydrograph (5)

However, it is realized that this relationship results in a steeper slope of the rising limb portion of the hydrograph than those results obtained by the previous two cases (Case I and Case II). In order to eliminate this discrepancy, the peak runoff rate is modified by

$$q_p = C\ i\ A\ \frac{t_r}{t_c} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (18)$$

Nevertheless, this peak runoff rate is still at a flow less than equilibrium. Under this condition, Henderson and Wooding (27) indicate that after the storm stops, the runoff rate will remain constant until a time t_p then the runoff recedes to zero. The value of t_p depends on t_r and t_c and is given by:

$$t_p = 0.4\ t_r + 0.6\ t_c \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (19)$$

Therefore, for $t_r < t_c$, the linearized subhydrograph procedure is modified as follows:

$$\text{For } t < t_r, \quad q_t = C\ i\ A\ \frac{t}{t_c} \ . \ . \ . \ . \ . \ . \ . \ . \quad (20)$$

$$\text{For } t \leq t \leq t_p, \ q_t = C\ i\ A\ \frac{t_r}{t_c} = q_p \ . \ . \ . \ . \ . \ . \quad (21)$$

$$\text{For } t > t_p, \quad q_t = C\ i\ A\ \frac{t_r}{t_c}\left(\frac{t_b - t}{t_b - t_p}\right) \ . \ . \ . \ . \ . \ . \quad (22)$$

where:

$$t_b = 0.6\ t_r + 1.4\ t_c \ . \ . \ . \ . \ . \ . \quad (23)$$

The runoff volume is determined by:

$$V = C\,i\,A\,t_r \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (24)$$

Figure 4 shows the modified subhydrograph for this case.

The runoff coefficient C is one of the most significant parameters that contribute to the proper determination of the rate of runoff. The coefficient represents the abstractions, or "losses", between rainfall and runoff generated from a particular subcatchment. These losses take into account the evaporation, infiltration, depression storage and surface wetting that takes place in the subbasin. It is noted that the abstractions decrease in magnitude as the duration of the storm increases. Various studies have been reported that relates the variation of runoff coefficients to the duration of rainfall (21). The Linearized Subhydrograph Method, (5, 24, 40) uses Hoad's runoff coefficients shown in Figure 5. The variation of Hoad's runoff coefficient is described by the following equations:

$$C = \frac{t}{t + 8} \text{ (impervious areas)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (25)$$

$$C = \frac{0.5t}{t + 15} \text{ (improved pervious areas)} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (26)$$

$$C = \frac{0.3t}{t + 20} \text{ (sandy pervious areas)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (27)$$

In the modified version presented herein, the values given by equations (26) and (27) for pervious area are averaged.

The time of concentration for a subbasin is equivalent to the inlet time, the time required for the surface runoff to flow from the most remote point of the subbasin to the inlet of the subbasin. It

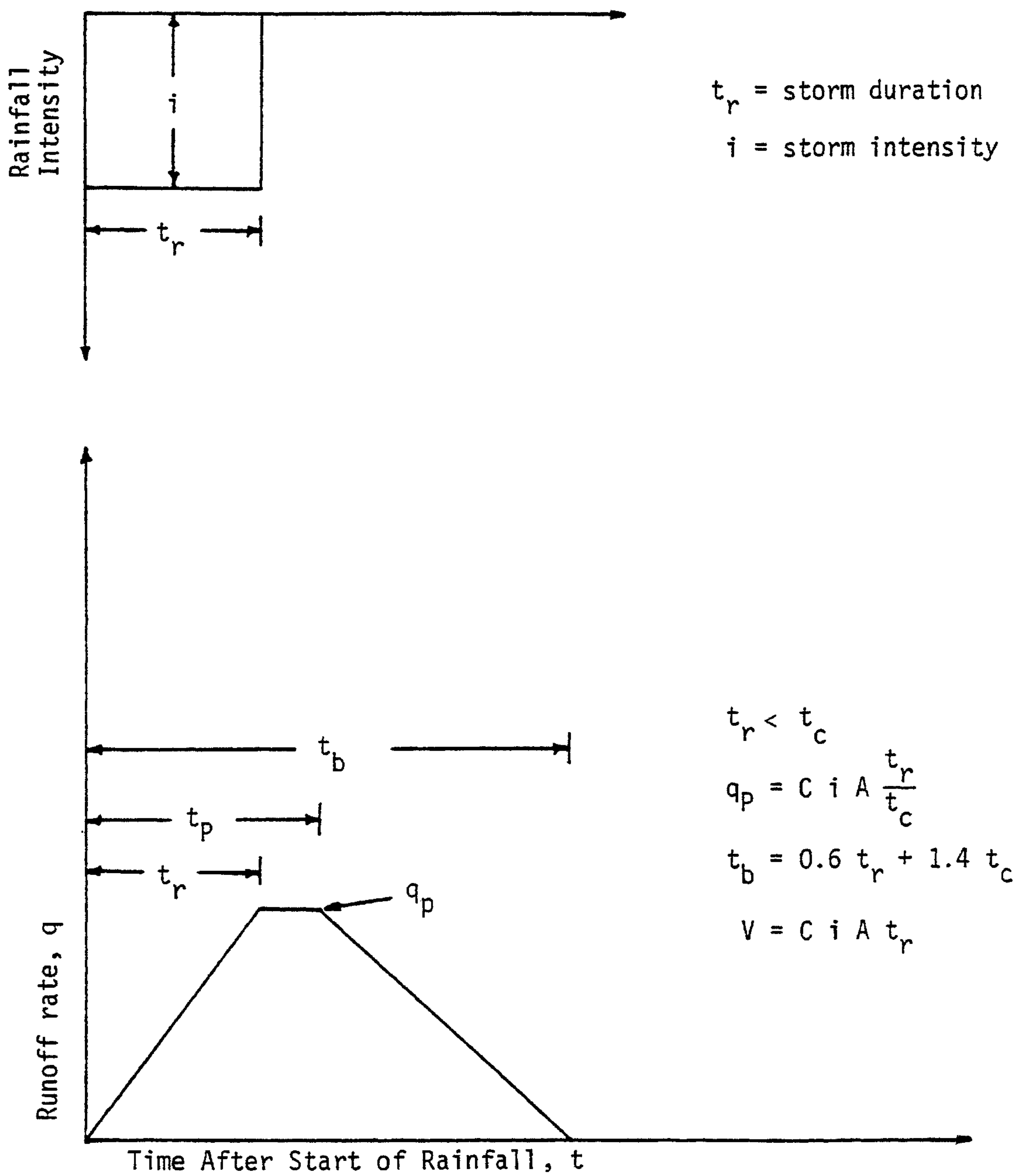


Figure 4 Case III Modified Linearized Subhydrograph

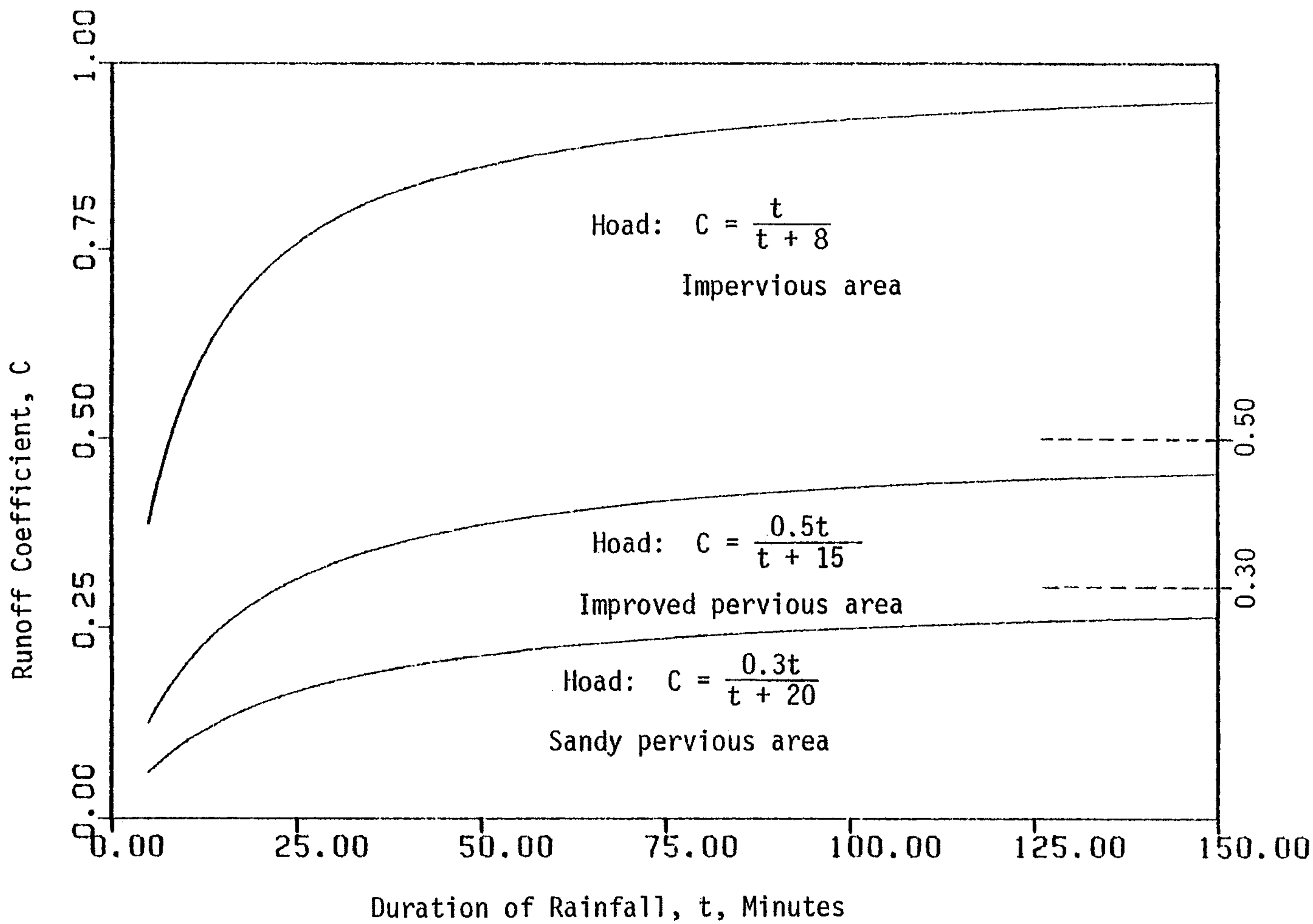


Figure 5 Runoff Coefficients vs Duration of Rainfall and Area Characteristics (21)

may also be described as the time to reach equilibrium, where the rate of runoff is equal to the rate of rainfall supply for a uniform rainfall intensity.

Various methods of estimating time of concentration for a drainage area have been proposed. For overland flow, a formula based on kinematic wave theory (27, 39) was adopted to be used in the model. The equation is given by the following relationship:

$$t_c = 0.928 \frac{L^{0.6} \quad N^{0.6}}{i^{0.4} \quad S^{0.3}} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (28)$$

where:

t_c = time of concentration (minutes)

L = length of overland flow (feet)

N = Manning's roughness coefficient

i = intensity of excess rainfall (inches/hour)

S = average overland slope (foot per foot)

Other equations that relate the time of concentration to physical characteristics of the basin are given below:

Kerby's formula (29) which is used for L < 1200 feet,

$$t_c = 0.83 \, (N \, L \, S^{-0.5})^{0.467} \quad . \ . \ . \ . \ . \ . \ . \ . \quad (29)$$

Airport drainage formula (22),

$$t_c = \frac{1.8 \, (1.1\text{-}C)\sqrt{L}}{(100S)^{0.333}} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (30)$$

Morgali and Linsley's formula (34),

$$t_c = 0.99 \frac{L^{0.593} N^{0.605}}{i^{0.388} S^{0.38}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \qquad (31)$$

where:

C = runoff coefficient

and other variables are as defined above.

Equations (29), (30), and (31) are incorporated in the MLSURM model on an optional basis in the determination of time of concentration for a given subcatchment.

For large subbasins with street curbs, the time of concentration is obtained by summing the overland time and the time of travel in the gutter. It is noted that the original version of the model (24, 40) does not take into account the gutter flow travel time. In the MLSURM model, however, the overland time for the impervious area or the pervious area is determined by using the distance from upstream portion of the impervious or pervious area to the gutter as overland length. Based on the overland time, an initial overland hydrograph contributing to the gutter is obtained by the linearized subhydrograph procedure. Gutter flow travel time computed according to the initial overland hydrograph is then included in the time of concentration to develop the inlet hydrograph.

In applications where sewered areas with subcatchments are considered, the hydrograph resulting from each subcatchment must be routed through the sewer system to obtain the outfall hydrograph. In order to satisfy this need, "time-offset" routing developed by Tholin (41) is utilized. The routing procedure is rather simple and is based on uniform flow conditions in the sewer pipe. The travel time in the sewer is determined by dividing the sewer length by the flow velocity corresponding to the "centroid discharge" of the inflow hydrograph. The inflow hydrograph is then offset according to the travel time. In this fashion the routed hydrographs are then utilized to develop system hydrographs at various points for the sewer network.

In case of combined sewer systems, the handling of waste water flow is based on procedures similar to those used in the SWMM model (8). This consists of predicting and distributing the waste water flow throughout the sewer system based on population, land use, home valuation, and other factors. The sewage flow is combined with the storm runoff. The combined sewer inflow is then routed through the sewer system by the "time-offset" method described above.

Quality Model

The development of the quality model centers on determining pollution levels of the storm water. Specifically surface pollutants, catchbasin pollutants and pollutants in the sewer are included in the model.

Surface pollutants consist of street litter and dustfall that accumulate on the ground and street surfaces prior to a storm. When the storm occurs, the accumulated materials on the surface are dissolved by rain. As rainfall continues, surface runoff begins to wash off the pollutants. The impact of the raindrops on the relatively rough surfaces provides a high level of turbulence which tends to accelerate the pollutant removal process.

Keeping in mind the complexity of the pollutant removal process, an attempt is made to develop a relationship that would be able to describe such phenomenon and aid in the proper simulation of the pollutant wash-off from the basin surfaces. The following assumptions are made in the development of such formula:

1. Decay effects of pollutants due to chemical changes and biochemical degradation during the runoff period are neglected.
2. Since the distribution of air pollutants in the atmosphere is nonuniform, spatially varied and unsteady, it is difficult to formulate the amount of pollutant which scavenges off by rainfall; therefore, this source of pollutant is not included.
3. The amount of pollutants percolating into the soil by infiltration is neglected.
4. The rate of washout of pollutants by surface runoff is assumed to be proportional to the amount of pollutant remaining on the surface, to the rate of runoff and the level of turbulence in the flow.

Assumption 4 then leads to the development of the following proportionality:

$$-\frac{dP}{dt} \propto P\ q\ u' \qquad (32)$$

where

P = amount of pollutant remaining on the surface

q = rate of runoff

u' = measure of turbulence level

t = elapsed time

As noted, u' represents the turbulence level and is given by the following proportionality:

$$u' \propto \frac{u^*}{y} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (33)$$

where:

u^* = shear velocity

y = depth of flow

For wide channels, the shear velocity is given as:

$$u^* = \sqrt{\frac{\tau_o}{\rho}} = \sqrt{\frac{\gamma y S}{\rho}} = \sqrt{g\ y\ S} \quad . \; . \; . \; . \; . \; . \; . \quad (34)$$

where:

τ_o = shear stress at the channel bed (lbf/ft^2)

ρ = density of water ($slug/ft^3$)

γ = specific weight of water (lbf/ft^3)

g = gravitational acceleration (ft/sec^2)

y = depth of flow (ft)

S = slope of channel (ft/ft)

Combining equation (32) and (33) with equation (34), gives:

$$-\frac{dP}{dt} = K\ P\ q\ \sqrt{\frac{S}{y}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (35)$$

Integrating equation (35) yields

$$P_t = P_o e^{\left(-K \int_0^t \sqrt{S}\ \frac{dV}{\sqrt{y}}\right)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (36)$$

where:

P_o = amount of pollutant on the surface before the onset of the storm (pounds)

P_t = amount of pollutant remaining on the surface at time t (pounds)

dV = incremental runoff volume during time interval dt (inches)

K = a proportionality constant

Equation (36) can be expressed as follows:

$$P_{t+\Delta t} = P_t \, e^{-K\sqrt{S}\,\frac{\Delta V}{\sqrt{y}}} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (37)$$

where:

$P_{t+\Delta t}$ = amount of pollutant remaining on the surface at time $t+\Delta t$ (pounds)

P_t = amount of pollutant on the surface at time t (pounds)

Δt = time interval (hour)

ΔV = incremental runoff volume during Δt (inches)

y = depth of surface runoff (inches)

S = overland slope (ft/ft)

K = proportionality constant

Thus, the rate of surface pollutant washout M_s in lbs/hour is:

$$M_s = (P_t - P_{t+\Delta t})/\Delta t = P_t(1-e^{-K\sqrt{S}\,\frac{\Delta V}{\sqrt{y}}})/\Delta t \quad . \ . \ . \ . \quad (38)$$

Equation (38) gives the amount of surface runoff pollutograph corresponding to the inlet hydrograph. The equation is applied successively, the value of $P_{t+\Delta t}$ determined at the end of the current interval becomes the value of P_t at the beginning of the next interval. The incremental runoff volume ΔV is computed by:

$$\Delta V = \bar{q}\,\Delta t = \tfrac{1}{2}(q_t + q_{t+\Delta t})\Delta t \quad \ldots\ldots\ldots\ldots \quad (39)$$

where

ΔV = incremental runoff volume (inches)

$\bar{q}$ = average runoff rate during Δt (inches/hour)

q_t = runoff rate at time t (inches/hour)

$q_{t+\Delta t}$ = runoff rate at time $t+\Delta t$ (inches/hour)

Δt = time interval (hour)

The depth of flow y is derived from the Manning's equation for overland flow and is given in the following form:

$$y = \left(\frac{\bar{q}\ N\ L}{1029.1\sqrt{S}}\right)^{0.6} \quad \ldots\ldots\ldots\ldots \quad (40)$$

where y = runoff flow depth (inches)

$\bar{q}$ = average runoff rate during Δt(inches/hour)

N = Manning's roughness coefficient

L = overland length (feet)

S = overland slope (feet per foot)

The rate constant K in equations (37) and (38) is an important paramater and its value varies with type of pollutants, surface characteristics, climatic conditions, etc. Due to the various uncertain factors involved, it would seem logical to empirically determine the value of K and incorporate surface characteristics and type of pollutants under consideration. This can be accomplished by using measured pollutant washoff data to calibrate the value of K so that model simulation results are close to the measured data.

Equation (38) is incorporated into the MLSURM model to yield the surface runoff pollutographs for soluble pollutants such as BOD, COD, coliforms, various forms of nitrogen, and hydrolyzable phosphates. However, in a study of street surface contaminants (12), a substantial amount of particulate material was found to reside inside cracks, in small pits, and within other street surface irregularities. This leads to the introduction of an "availability factor" which accounts for the reduction of the amount of nonsoluble pollutants that can be washed off as suspended solids. The factor is a function of runoff rate. In the SWMM model (8), an equation in the following form is proposed:

$$\overline{A} = .057 + 1.4\ (\overline{q})^{1.1} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \qquad (41)$$

where:

$\overline{A}$ = availability factor

$\bar{q}$ = runoff rate (inches/hour)

This equation is derived using the data from a Cincinnati study (8). Although the equation seems site specific, it is used in the MLSURM model until a more reliable relationship can be obtained. Thus, the pollutant washout equation for suspended solids with the introduction of availability factor becomes:

$$M_s = P_t\ \overline{A}\ (1 - e^{-K\sqrt{S}\ \frac{\Delta V}{\sqrt{y}}})/\Delta t \quad . \ . \ . \ . \ . \qquad (42)$$

Equations (38) and (42) attempt to model the surface pollutant removal process with the following restrictions:

1. For catchments subjected to identical rainfall input, the one with steeper overland slope would result in faster pollutant removal rate.
2. For a particular catchment where overland slope is fixed, the motive force of washing out the pollutant then depends on the ratio, $\Delta V/\sqrt{y}$. The higher this ratio, the more significant the motive force becomes in washing out the surface pollutant. This relationship indicates the effect of incremental runoff volume and the effect of the depth of flow upon pollutant removal efficiency.

Catchbasins constructed with inlet combinations are used to remove heavy grit and debris carried by runoff for the duration of storm. However, the organic material contained in the trapped pocket in the form of liquids and solids will undergo decomposition between storms. Hence, catchbasins will contribute a substantial amount of organic pollutants to the runoff process if they are not cleaned prior to a storm event.

A study undertaken by APWA (1) describes the way soluble pollutants in a catchbasin are flushed into the sewer by runoff. Based on the results of this study, Metcalf and Eddy, Inc. (32) developed an equation that determines the amount of pollutant removed from a catchbasin as follows:

$$PER = 100\ (1.0 - e^{-\frac{V}{1.6G}}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (43)$$

where:

PER = per cent of catchbasin pollutant removal

V = cumulative inflow volume to catchbasin (ft^3)

G = trapped volume of liquid in catchbasin before the storm (ft^3)

Therefore, for a time increment Δt, the rate of catchbasin pollutant flushout M_c can be computed by:

$$M_c = P_c \left(e^{-\frac{V_t}{1.6G}} - e^{-\frac{V_{t+\Delta t}}{1.6G}}\right)/\Delta t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (44)$$

where

P_c = amount of catchbasin pollutant at the onset of storm runoff (pounds)

V_t = cumulative inflow volume to the catchbasin, at time t (ft^3)

$V_{t+\Delta t}$ = cumulative inflow volume to the catchbasin, at time $t+\Delta t$ (ft^3)

Δt = time interval (hour)

In applications to watersheds with sewer systems, the pollutographs entering into the sewers must be routed to yield the outfall pollutograph. For simplicity in routing the pollutants through the sewer system, it is assumed that the decay effects due to chemical and biochemical changes are negligible, and that mixing within each sewer section in the system is instantaneous and complete. The methodology is based on the concept of mass balance, that is

$$\left\{\begin{array}{c}\text{amount of pollutant}\\ \text{in the sewer at}\\ \text{next "time - step"}\end{array}\right\} \equiv \left\{\begin{array}{c}\text{amount of pollutant}\\ \text{in the sewer at}\\ \text{present "time-step"}\end{array}\right\} + \left\{\begin{array}{c}\text{amount of}\\ \text{pollutant}\\ \text{entering}\end{array}\right\} - \left\{\begin{array}{c}\text{amount of}\\ \text{pollutant}\\ \text{leaving}\end{array}\right\} \quad . \; . \; . \; . \; . \; . \qquad (45)$$

In mathematical form, the mass balance relationship reads:

$$(C\,\overline{V})_{n+1} = \left\{ (C\,\overline{V})_n + \frac{(C_{in}\,\overline{V}_{in})_n + (C_{in}\overline{V}_{in})_{n+1}}{2} - \frac{(C_{out}\overline{V}_{out})_n + (C_{out}\overline{V}_{out})_{n+1}}{2} \right\} \qquad (46)$$

where

C = concentration of pollutant in the sewer (pounds/ft^3)

$\overline{V}$ = volume of flow in the sewer (ft^3)

n = "time - step" index

C_{in} = inflow concentration of pollutant (pounds/ft^3)

$\overline{V}_{in}$ = inflow volume (ft^3)

C_{out} = outflow concentration of pollutant (pounds/ft^3)

$\overline{V}_{out}$ = outflow volume (ft^3)

Manipulation of the equation (46), accompanied with the assumption of complete mixing, yields the following equation:

$$C_{n+1} = \frac{C_n\left[\frac{2\overline{V}_n}{\Delta t} - (Q_{out})_{n+1}\right] + (C_{in}Q_{in})_n + (C_{in}Q_{in})_{n+1}}{\left[\frac{2\overline{V}_{n+1}}{\Delta t} + (Q_{out})_{n+1}\right]} \quad . \; . \; . \qquad (47)$$

where:

$C = C_{out}$, outflow concentration of pollutant (pounds/ft^3)

C_{in} = inflow concentration of pollutant (pounds/ft^3)

Q_{out} = outflow discharge at downstream end of the sewer (ft^3/sec)

Q_{in} = inflow discharge at upstream end of the sewer (ft^3/sec)

$\overline{V}$ = volume of flow in the sewer (ft^3)

Δt = time interval (sec)

n = "time-step" index

Equation (47) is incorporated in the model to route the soluble pollutants through the sewer system. To deal with the routing of suspended solids, an additional sediment uptake and deposition procedure similar to that used in the SWMM model (8) is incorporated in the model developed herein.

In case of combined sewer systems, the strength of suspended solids, BOD, and coliforms of sewage flow were determined according to land use, family income level, and other factors (8). These contributions were then superimposed on the respective surface runoff pollutographs. The combined pollutographs were then routed through the sewer system.

CHAPTER IV

DETAILS OF THE COMPUTER PROGRAM

The computer model developed herein follows the conceptual developments of quantity and quality simulation presented in Chapter III. The model is divided into a main driving program and 43 subprograms. A generalized flowchart that shows the basic quantity and quality simulation algorithms is shown in Figure 6.

The object-time dimension feature of FORTRAN IV is utilized to allocate the adjustable dimension variables into a single one-dimensional array labeled S. The size of the array S is declared by the blank COMMON statement in the main program. During execution of the program, the size of S is checked dynamically to insure that there are sufficient memory storages for the allocation of adjustable dimension variables. If the storages reserved for the array is insufficient, the program features the printing of an error message and the execution terminates. It is, then, necessary to increase the size of the S array in the main program.

The following gives a brief description of each component of the program.

MAIN Program

In addition to declaring the value of dimension of the S array, the program assigns the same value for the variable MSOS which

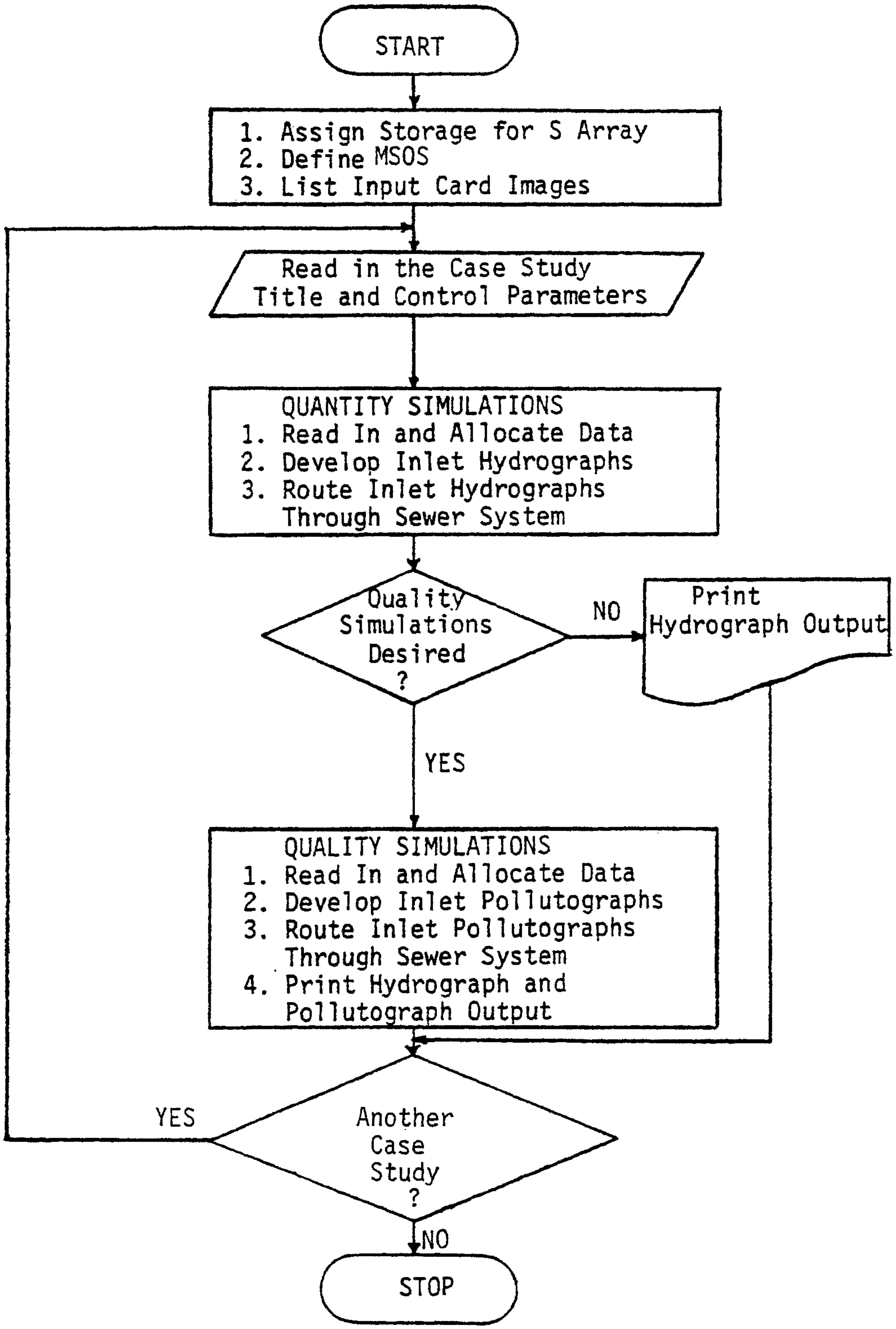


Figure 6 Generalized Flowchart of MLSURM Model

represents the maximum storages reserved for the array. The value of MSOS is dynamically checked by the program during the execution. Therefore, whenever the magnitude of the dimension of S array is changed, the associated value of MSOS must also be changed. Program MAIN then calls the subroutine CARD to produce a card image listing of the input data cards. Further, the subroutine XQTION is called to drive the execution of the quantity and quality simulation.

Supportive Subprograms

1. XQTION

   Reads in case study title and the simulation control parameters.

2. QNTITY

   Coordinates other quantity simulation subroutines in the generation of hydrographs.

3. INPUT

   Reads in general quantity and quality simulation parameters such as number of subcatchments, number of sewer pipes, number of raingages, number of quality parameters, etc.

4. QNDATA

   Reads in the rainfall data and the surface physical data.

5. QNDWF

   Reads in data related to dry weather flow in combined sewer systems and calculates dry weather flow quantity for each subcatchment.

6. QNPRSF

   Reads in the flows related to identifiable industrial processes and adjusts the predicted dry weather flow.

7. SWRDAT

    Reads in the sewer system conduit data such as sewer length, invert slope and roughness coefficients.

8. INITAL

    Initializes the travel time of flow in gutters.

9. QNSURF

    Performs the quantity simulation of surface runoff to produce inlet hydrograph.

10. CONTIM

    Estimates overland flow time of concentration for the development of subhydrograph in conjunction with the QNSURF subroutine.

11. SUBHY

    Develops and superimposes the subhydrographs generated from impervious and pervious areas according to the three cases of the Linearized Subhydrograph Method.

12. GUTTER

    Estimates travel time in the gutter which is then included in the time of concentration.

13. QNROUT

    Routesinlet hydrographs through the sewer systems to obtain outfall hydrographs.

14. QNCOMB

    Combines the surface runoff hydrograph with dry weather flow hydrograph in the case of combined sewer system.

15. PQNROU

    Calculates the flow travel time in sewer conduits. In case of the design mode, this subroutine will size the conduit dimensions according to the peak discharge.

16. SURCHG

    Regulates the inflow hydrograph of the surcharged conduit when the conduit's capacity is exceeded.

17. OFFSET

    Offsets the conduit inflow hydrograph to produce the outflow hydrograph according to the time-offset method.

18. AOUTPU

    Performs the output printing of simulated surface runoff hydrographs and sewer conduit hydrographs.

19. QLTITY

    Coordinates other quality simulation subroutines in the generation of pollutographs.

20. POLLID

    Supplements INPUT subroutine to read in the pollutant consitutent identification codes and the proportionality constant K.

21. QLDATA

    Reads in the surface quality data such as land use, street curb length, and catchbasin characteristics.

22. QLDWF

    Reads in the dry weather flow quality data and computes pollutants resulting from dry weather flow.

23. QLPRSF

    Supplements QLDWF subroutine to read in the industrial process flow characteristics for adjustment of dry weather flow quality prediction.

24. DDLOAD

    Computes the amount of pollutant on the surface prior to the storm based on the assumption of linear build up of dust and dirt.

25. SORTSS

Sets flag for suspended solids since the procedure involved in the simulation of suspended solids is somewhat different.

26. VOLSAV

Computes the average flow volume and hydraulic radius in conduits. This information is then stored on tape. Three scratch tapes are used in the program; namely tape 11, tape 12, tape 13. Tape 11 and tape 12 stores sewer conduit upstream inflow hydrographs and average flow volumes, respectively. These two tapes must be supplied whenever quality simulation is specified. Tape 13 which stores sewer flow hydraulic radius is utilized whenever suspended solids simulation is desired.

27. DWLOAD

Computes the initial bed load of solids buildup due to dry days during which the sewer was not flushed.

28. QLLOOP

Coordinates the simulation of pollutographs. For each quality constituent, the program calls QLSURF to simulate runoff pollutant removal process. Then, the QLROUT subroutine is called to route the inlet pollutographs through the sewer system. Finally, the BOUTPU subroutine is called to print the simulated hydrographs and pollutographs.

29. QLSURF

Simulates the surface pollutant washoff process to produce the inlet pollutographs for each subcatchment.

30. QLROUT

Routes the inlet pollutographs through the sewer system to produce the system outfall pollutograph.

31. CACHBS

Simulates pollutant removal process from catchbasins.

32. QLCOMB

Combines the catchbasin routed surface runoff pollutograph with sanitary flow pollutograph to form the sewer inflow pollutograph.

33. ZEROS

Establishes the initial conditions of sewer flow for the purpose of quality routing.

34. BOUTPU

Prints the simulation results mainly hydrographs and pollutographs.

35. CARD

Produces a card image listing of the input file.

36. SIZE

Dynamically checks the size of the S array to insure sufficient storage for memory allocation.

37. RMCARD

Lists the remaining input data cards which have not been read in when an error occurred causing the termination of execution.

38. VINTPO

Finds the ratio of partly filled sewer flows velocity to full flow velocity by a cubic spline interpolation function (28). Evenly spaced data are obtained from the hydraulic element graphs for circular conduits (3), semi-elliptical conduits, and egg-shaped conduits (31).

39. AINTPO

Finds the ratio of partly filled flow area to full flow area using procedure similar to that in VINTPO subroutine.

40. HINTPO

Finds the ratio of partly filled flow hydraulic radius to full flow hydraulic radius using procedure similar to that in VINTPO subroutine.

41. NEWTON

Solves the depth of flow by Newton-Raphson Method (28) for rectangular box sewer conduits and trapezoidal open channel according to Manning's formula.

42. FRCTLG

Finds the fraction of sewer sediments with diameter greater than or equal to the critical diameter. This fraction is used for the calculation of sediment uptake and deposition of suspended solids. A sieve analysis curve based on Chicago data (8) is used. However, if sieve analysis of local sewer sediments have been taken, this subprogram should be revised accordingly.

43. BLOCK DATA

Supplies the default values of accumulation rates of dust and dirt as shown in Table I and the pollutant content of dust and dirt as shown in Table II. These values are used to calculate the initial amount of pollutants on surface and can be replaced with field data if available.

The structure diagrams of the MAIN program, the QNTITY subprogram and the QLTITY subprogram are given in Figures 7, 8, and 9, respectively. Advantages in the program's memory storage allocation make it compatible with standard compilers so that computer systems comparable to that of the IBM 370, or UNIVAC 1108 can be used.

TABLE I Accumulation Rate of Dust and Dirt (1)

LAND USE	Accumulation Rate of Dust and Dirt (pounds/ dry day / 100 ft - curb)
Single Family Residential	0.7
Multiple Family Residential	2.3
Commercial	3.3
Industrial	4.6
Undeveloped and Park	1.5

TABLE II Pollutant Content of Dust and Dirt for Each Land Use Type (1)

Quality Constituent	Single Family Residential	Multi-Family Residential	Commercial	Industrial	Undeveloped or Parks
SS(mg/g)	1000.0	1000.0	1000.0	1000.0	1000.0
BOD(mg/g)	5.0	3.6	7.7	3.0	5.0
Coliforms (MPN/g)	1.3×10^6	2.7×10^6	1.7×10^6	1.0×10^6	0.0
COD (mg/g)	40.0	40.0	39.0	40.0	20.0
N (mg/g)	0.48	0.61	0.41	0.43	0.05
PO_4 (mg/g)	0.05	0.05	0.07	0.03	0.01

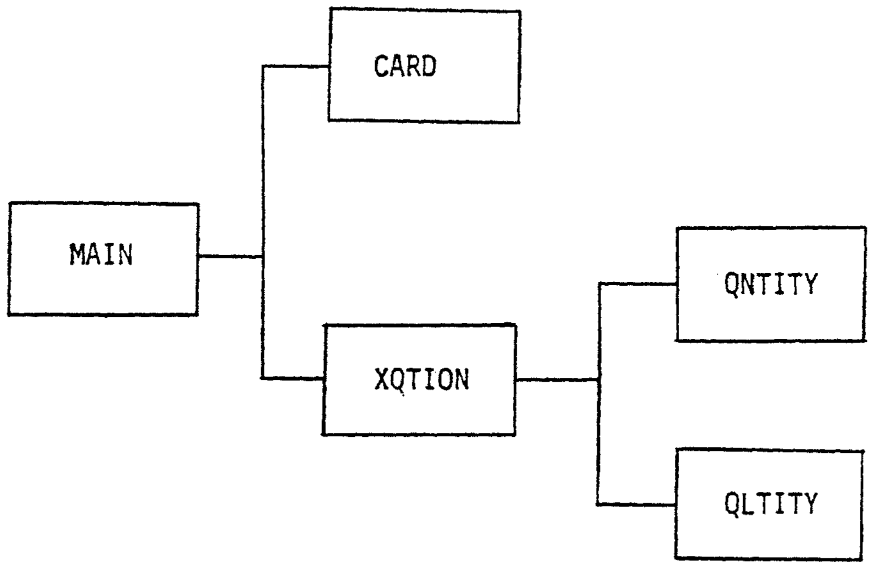


Figure 7 Structure Diagram of the Program MAIN

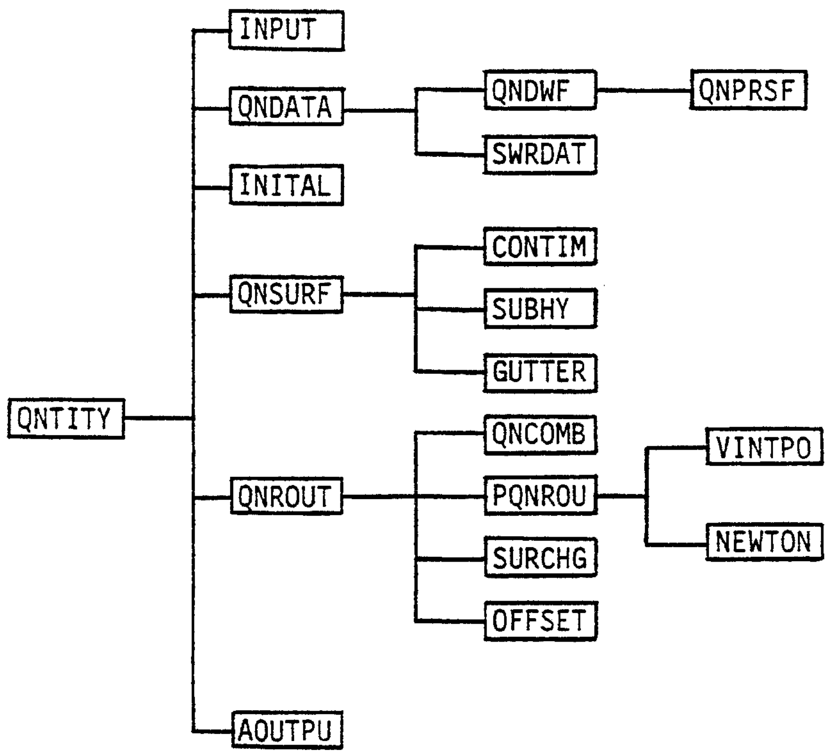


Figure 8 Structure Diagram of the Subprogram QNTITY

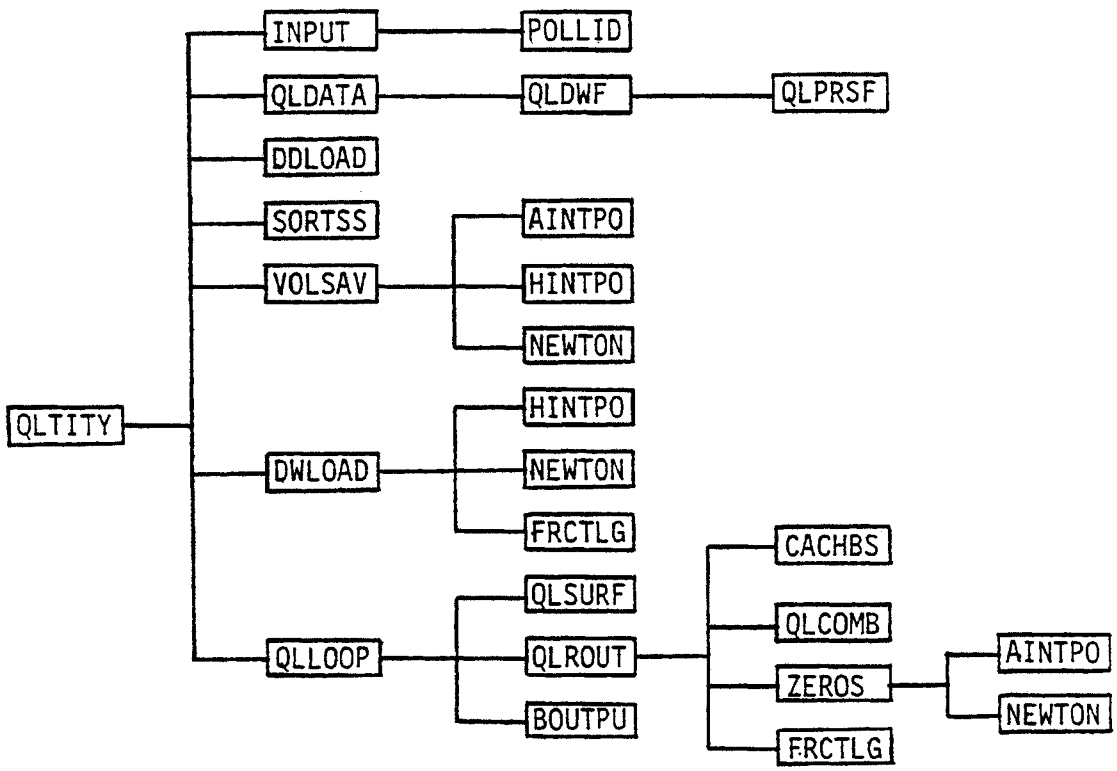


Figure 9 Structure Diagram of the Subprogram QLTITY

CHAPTER V

SENSITIVITY ANALYSES

The sensitivity of the model response due to the variation of the input parameter value was tested by applying the model to a hypothetical watershed. The procedure consisted of setting a data base to produce a set of "controlled" hydrographs and pollutographs. The value of the parameters to be tested was then varied within a certain range. The resulting hydrographs and pollutographs were then compared to the "controlled" hydrograph and pollutograph.

Sensitivity of Hydrograph Simulation

The surface physical data such as area imperviousness, overland length, overland slope, and Manning's roughness coefficient were tested by incrementing or decrementing their values by a certain amount. The resulting peak discharges and hydrograph patterns were then compared to those values obtained from the "controlled" hydrograph. The results obtained from this comparison are given in Table III. It is noted that the model did not produce appreciable changes in the peak discharges and the flow volumes when the variation of the overland length, slope, and Manning's roughness coefficient was less than or equal to 20% for both the pervious and impervious areas. However, when the magnitude of fraction of imperviousness was varied, a noticeable change resulted in the peak discharge and the total flow volume.

TABLE III Sensitivity Results of Hydrograph Simulation of Various Surface Parameters

Parameter	% Change in Input Parameter Value	% Change in Peak Discharge	% Change in Flow Volume
Imperviousness	+20	+16.6	+8.9
	+10	+ 8.1	+4.5
	+ 5	+ 4.3	+2.3
	- 5	- 3.9	-2.2
	-10	- 8.8	-4.6
	-20	-15.4	-9.1
Pervious Area Overland Length	+20	- 1.7	-1.8
	+10	- 1.0	-1.0
	+ 5	- 0.5	-0.5
	- 5	+ 0.5	+0.5
	-10	+ 1.0	+1.0
	-20	+ 2.6	+2.0
Impervious Area Overland Length	+20	small	small
	+10		
	+ 5		
	- 5		
	-10		
	-20		
Pervious Area Overland Slope	+20	+ 0.9	+0.0
	+10	+ 0.4	+0.4
	+ 5	+ 0.2	+0.2
	- 5	- 0.3	-0.3
	-10	- 0.5	-0.5
	-20	- 1.1	-1.1
Impervious Area Overland Slope	+20	small	small
	+10		
	+ 5		
	- 5		
	-10		
	-20		
Pervious Area Roughness Coefficient	+20	- 1.7	-1.8
	+10	- 1.0	-1.0
	+ 5	- 0.5	-0.5
	- 5	+ 0.5	+0.5
	-10	+ 1.0	+1.0
	-20	+ 2.6	+2.0

TABLE III (continued) Sensitivity Results of Hydrograph Simulation of Various Surface Parameters

Parameter	% Change in Input Parameter Value	% Change in Peak Discharge	% Change in Flow Volume
Impervious Area	+20	small	small
Roughness Coefficient	+10		
	+ 5		
	- 5		
	-10		
	-20		

Similarly, the results of sensitivity tests related to the sewer length, invert slope, and Manning's roughness coefficient are given in Table IV. From the results, it is seen that the model does not yield significant changes when magnitude of the sewer length, invert slope, and Manning's roughness coefficient was varied within a 20% range.

Sensitivity of Pollutograph Simulation

The parameter selected for the investigation of pollutograph variation consisted of the number of dry days (DRYDAY), the length of curb (CURB), and the rate constant K in equation (38). Six "controlled" pollutographs for the quality constituents BOD, coliform, COD, nitrogen, phosphate, and suspended solids were obtained by using those values of the number of dry days $(\text{DRYDAY})_c$, the length of curb $(\text{CURB})_c$, and the rate constant K_c in the "controlled" data base. The value of the parameter being tested was then multiplied by a factor of 2 to generate the pollutograph which was compared to the "controlled" pollutograph. Figures 10 to 15 show the deviation of the pollutographs due to the variation of the parameter DRYDAY. It is noted that the model is quite sensitive to the number of dry days. The pollutograph variations due to the increase of curb length are shown in Figures 16 to 21. The effects of CURB and DRYDAY are similar, since they determine the total amount of pollutant on the basin surface prior to the storm. The model responds well to the proportional rate constant K. Moreover, it is found that a greater K value produces higher mass emission rates, for soluble pollutants, during early periods of the storm. In other

TABLE IV Sensitivity Results of Hydrograph Simulation of Various Sewer Parameters

Parameter	% Change in Input Parameter Value	% Change in Peak Discharge	% Change in Flow Volume
Sewer Length	+ 20	- 4.1	- 0.8
	+ 10	- 2.2	- 0.4
	+ 5	- 1.0	- 0.2
	- 5	+ 1.0	+ 0.2
	- 10	+ 2.0	+ 0.3
	- 20	+ 4.0	+ 0.6
Invert Slope	+ 20	small	small
	+ 10		
	+ 5		
	- 5		
	- 10		
	- 20		
Manning's Roughness Coefficient	+ 20	small	small
	+ 10		
	+ 5		
	- 5		
	- 10		
	- 20		

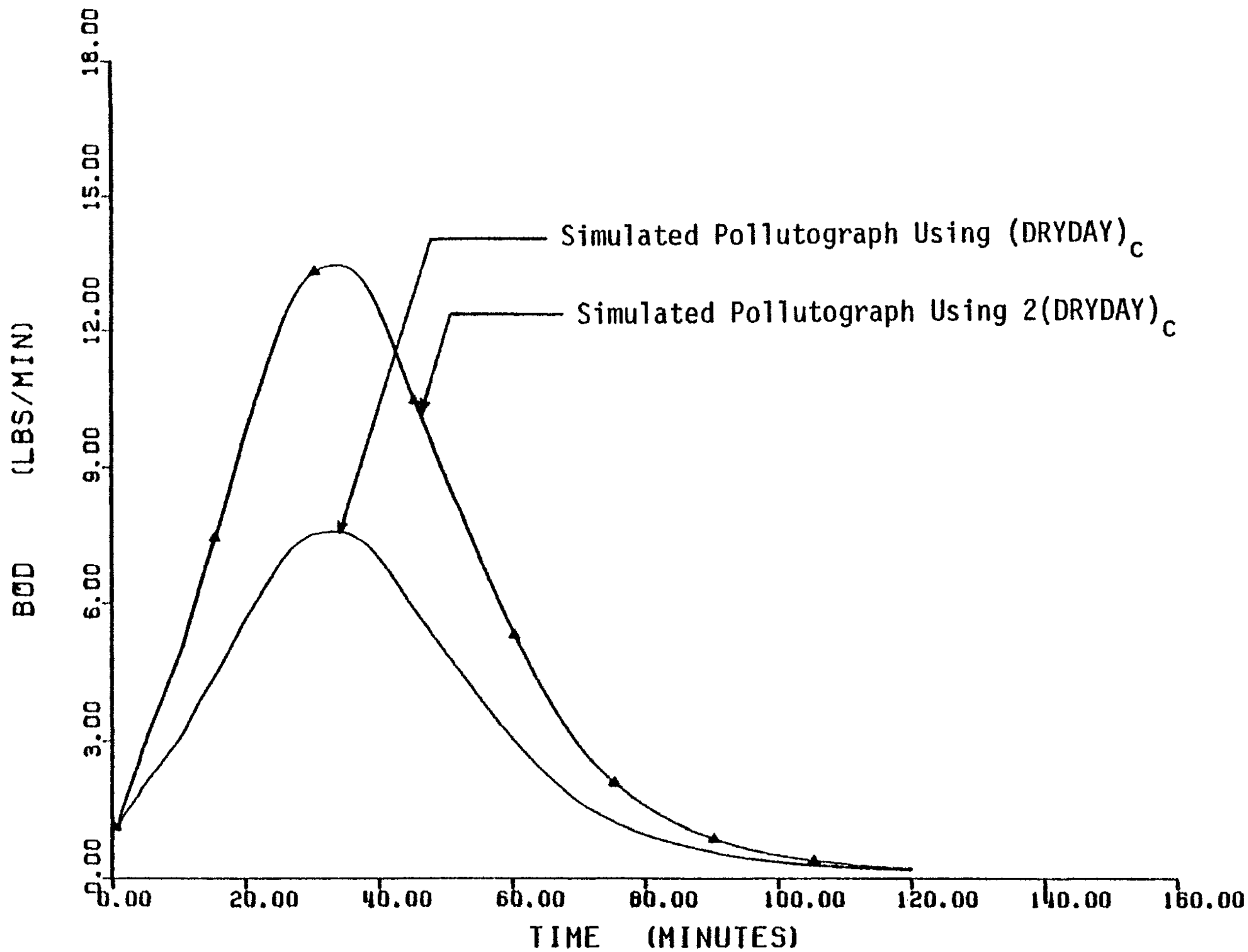


Figure 10 Effect of DRYDAY on BOD Pollutograph Simulation

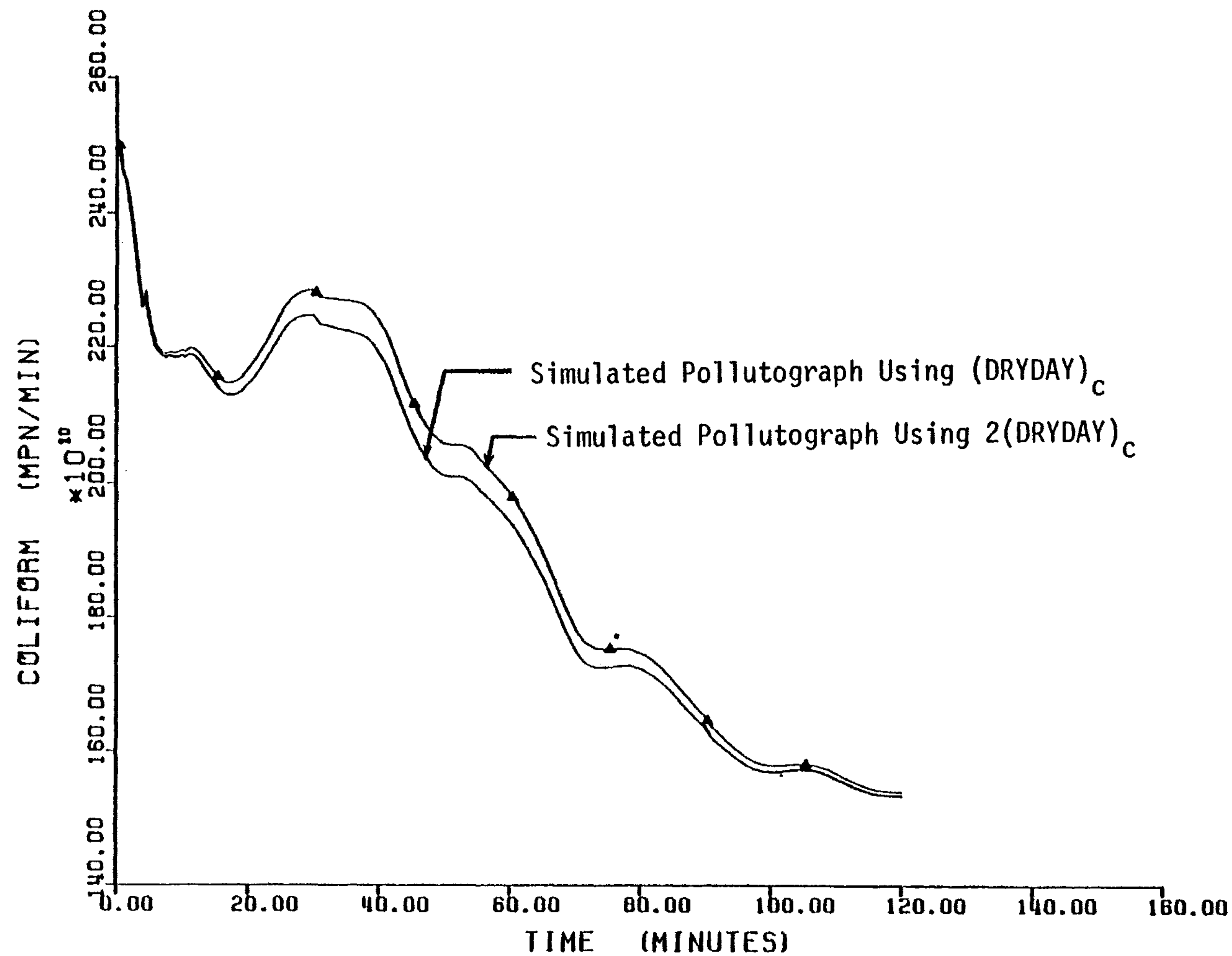


Figure 11 Effect of DRYDAY on Coliform Pollutograph Simulation

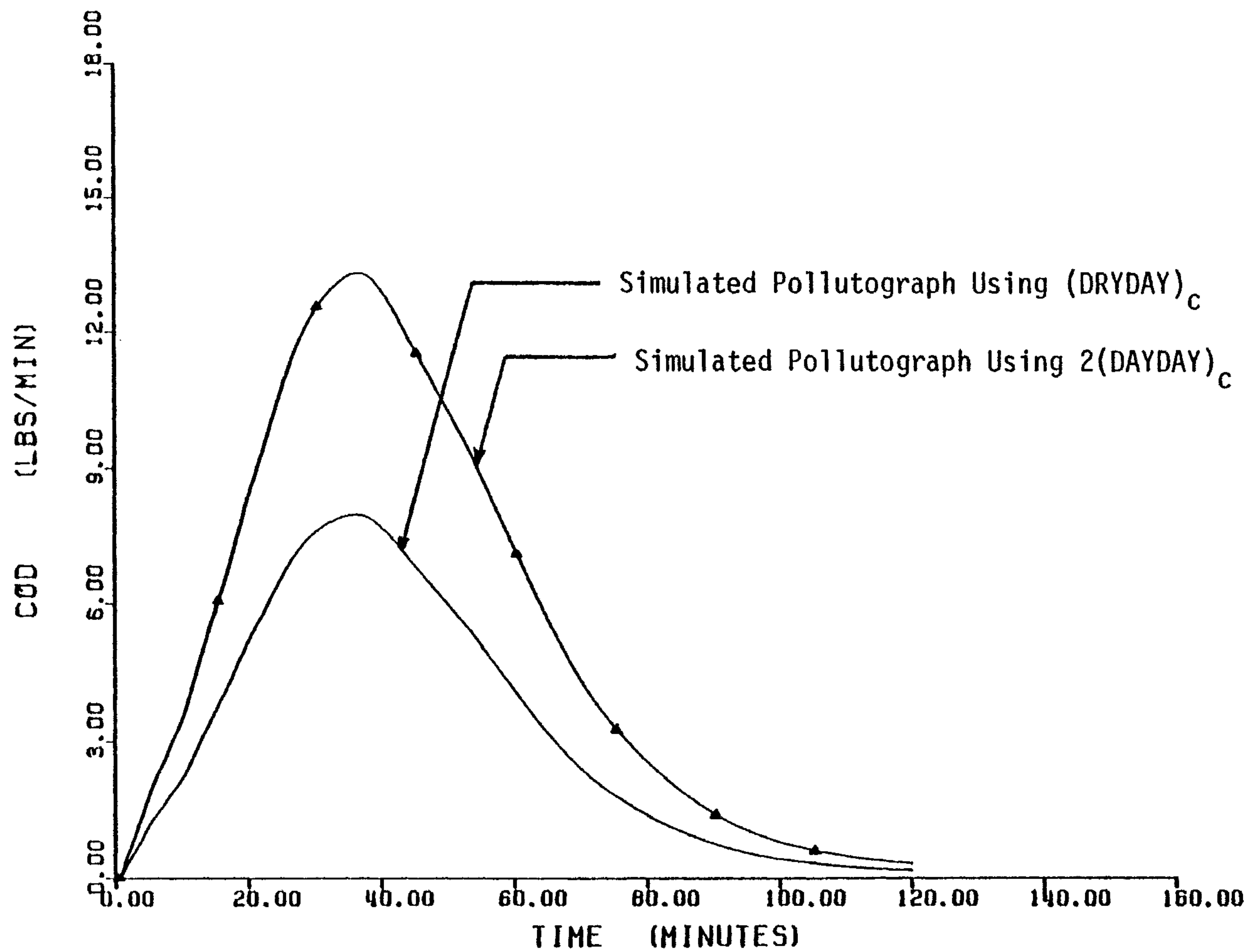


Figure 12 Effect of DRYDAY on COD Pollutograph Simulation

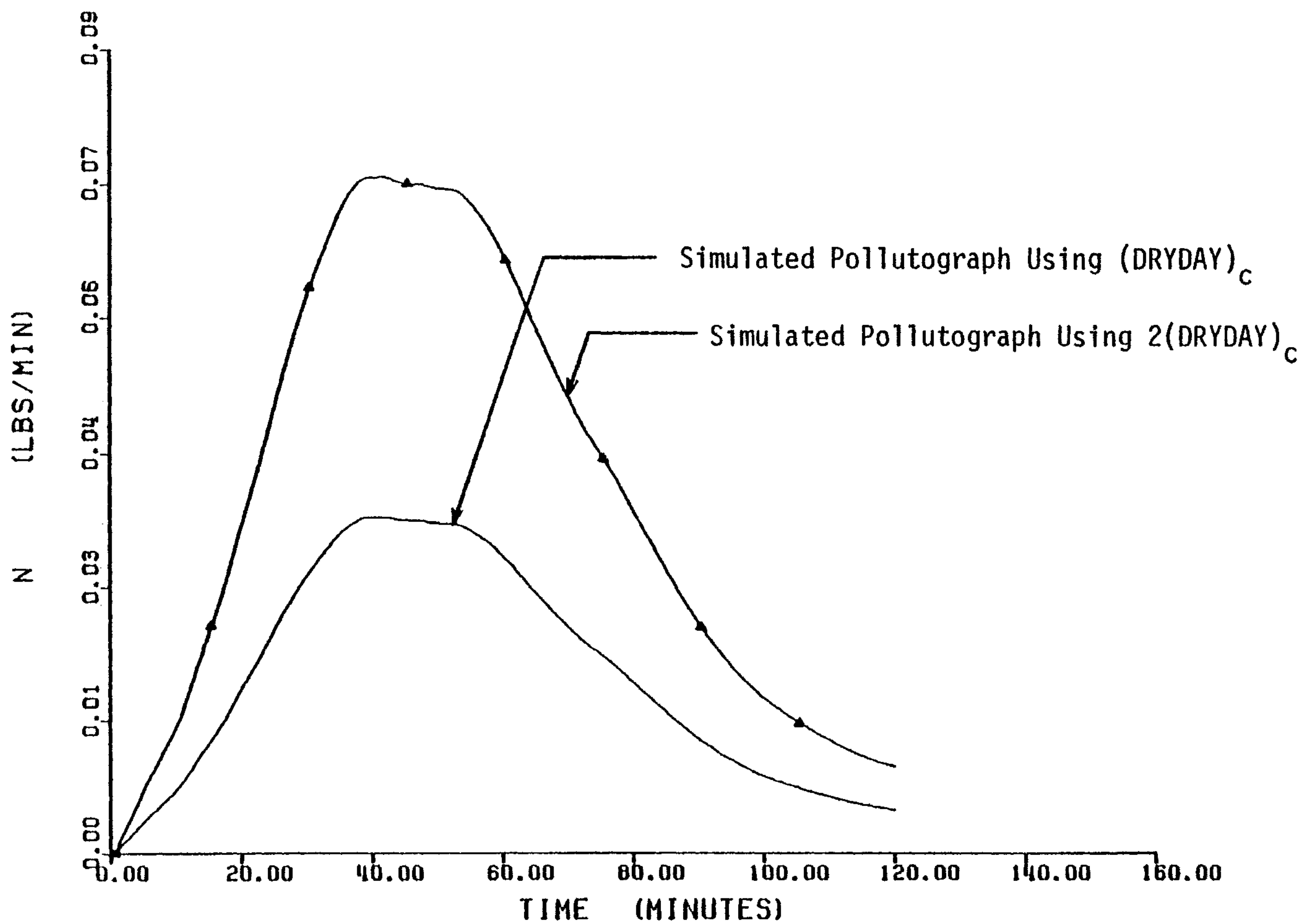


Figure 13 Effect of DRYDAY on Nitrogen Pollutograph Simulation

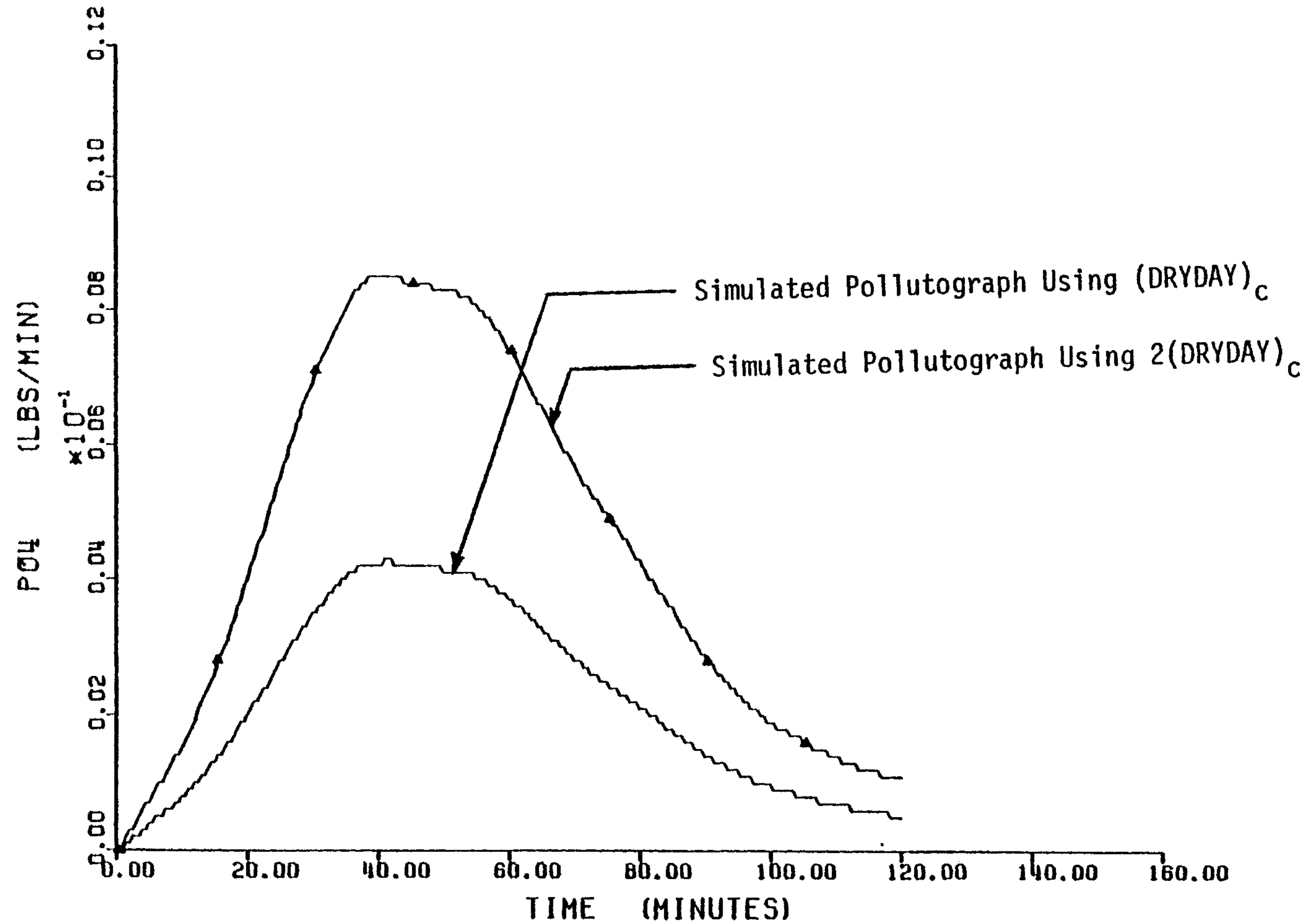


Figure 14 Effect of DRYDAY on Phosphate Pollutograph Simulation

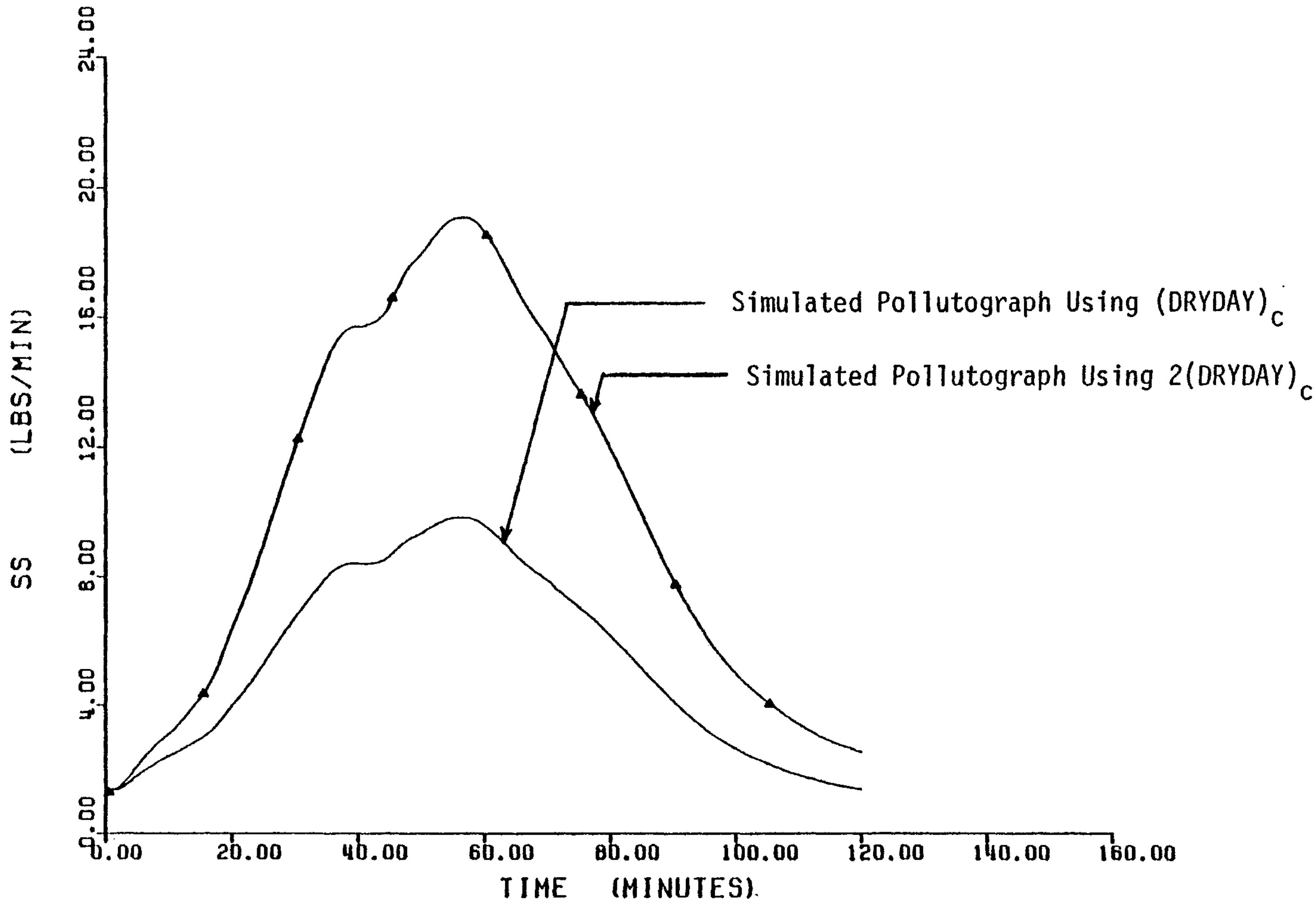


Figure 15 Effect of DRYDAY on Suspended Solids Pollutograph Simulation

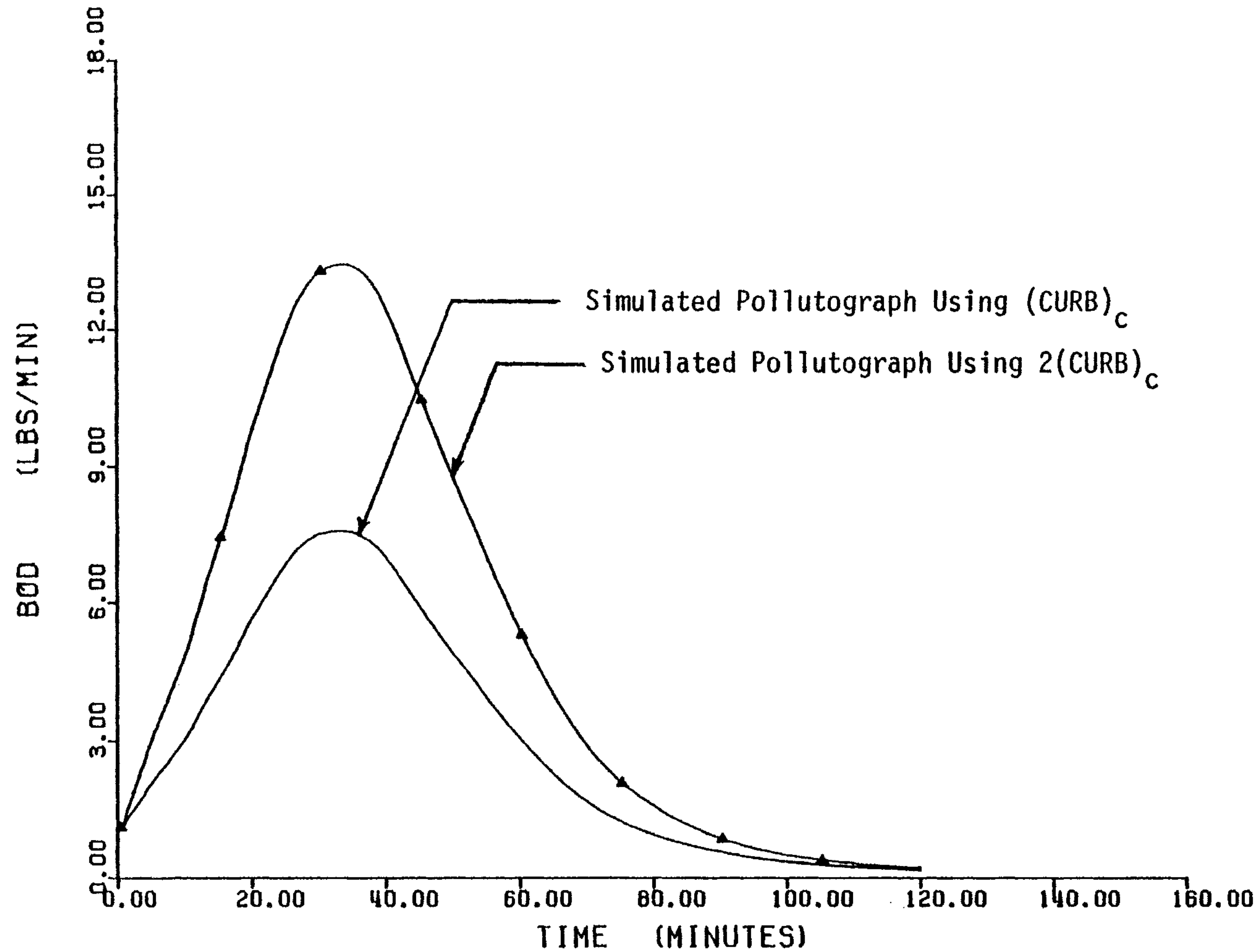


Figure 16 Effect of CURB on BOD Pollutograph Simulation

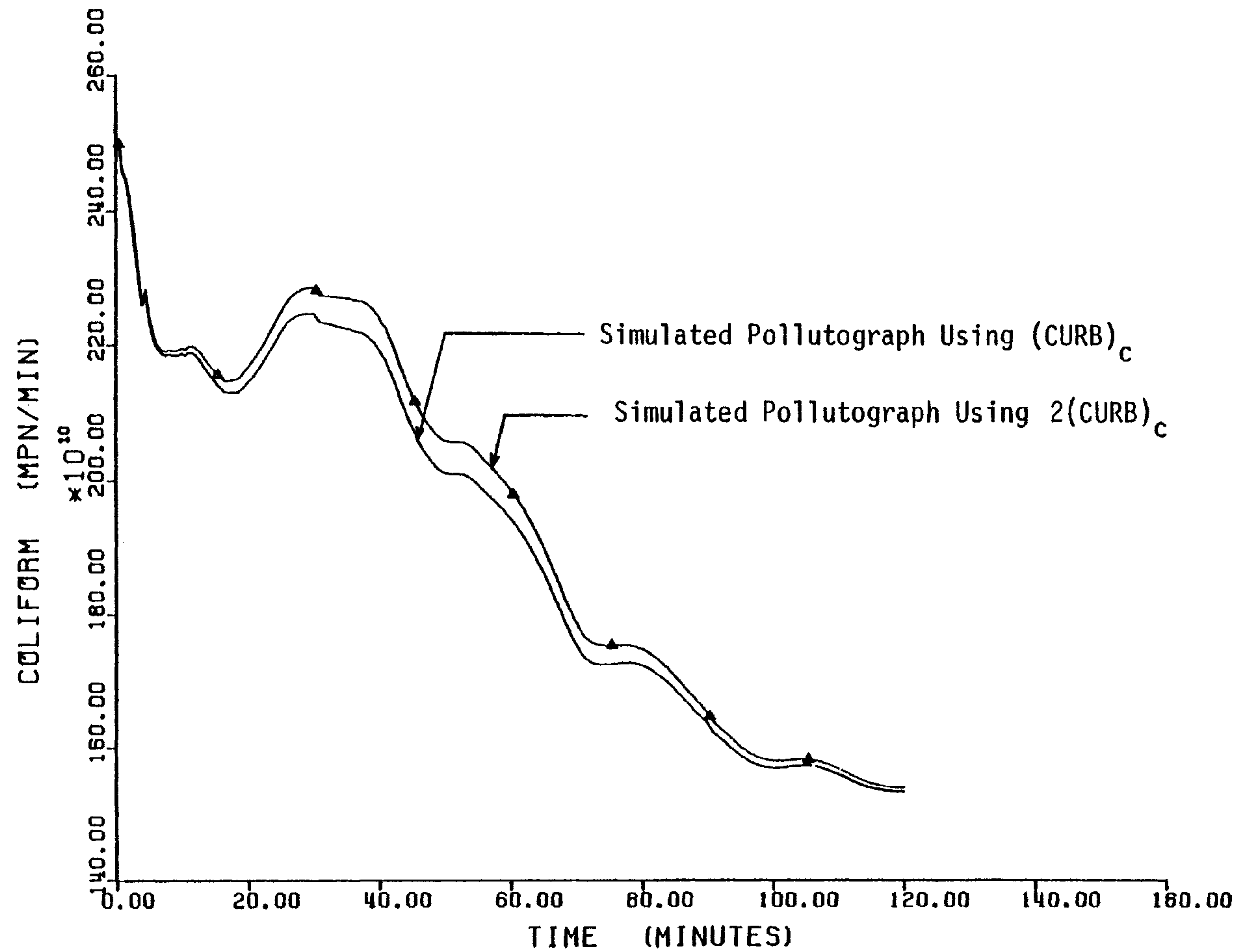


Figure 17 Effect of CURB on Coliform Pollutograph Simulation

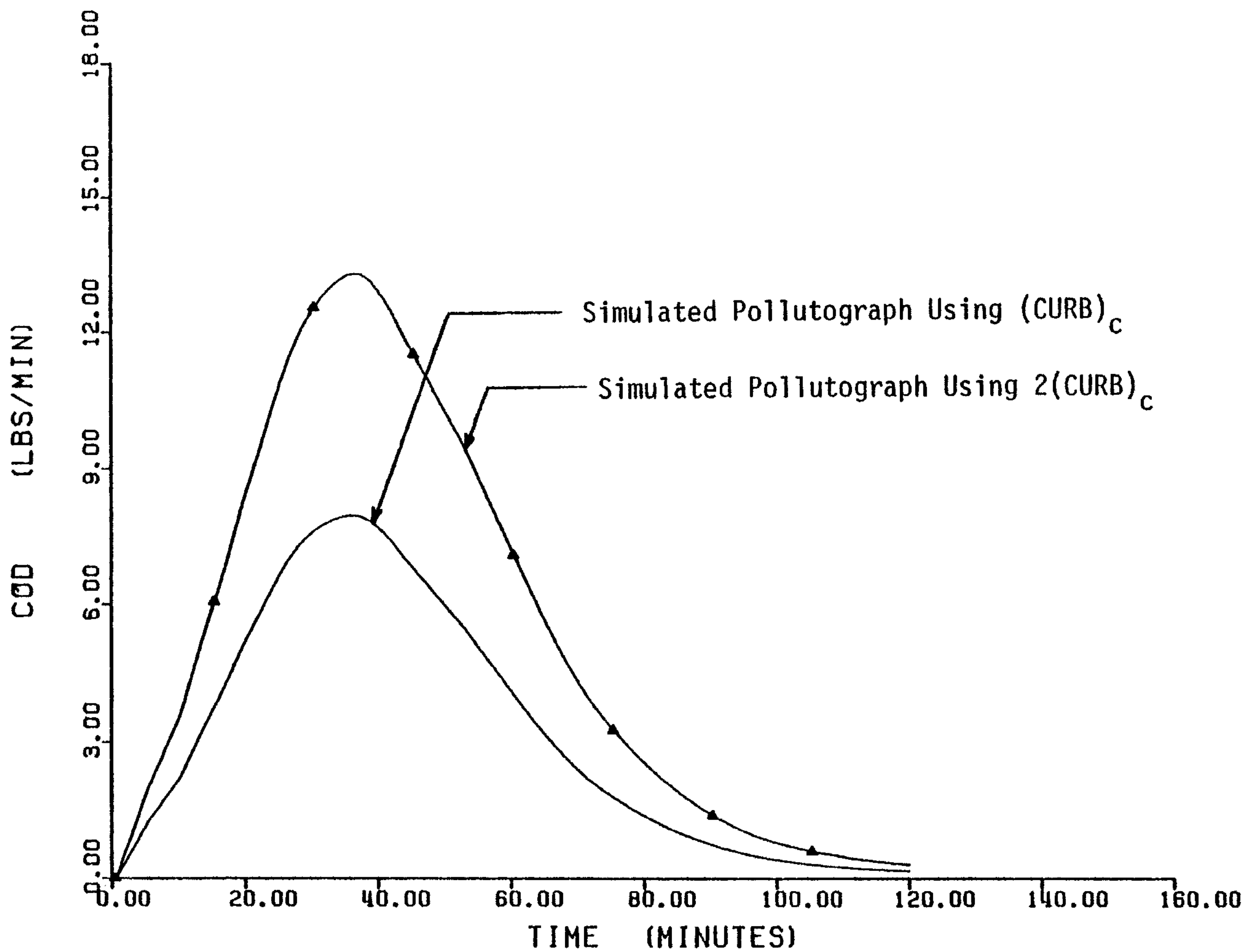


Figure 18 Effect of CURB on COD Pollutograph Simulation

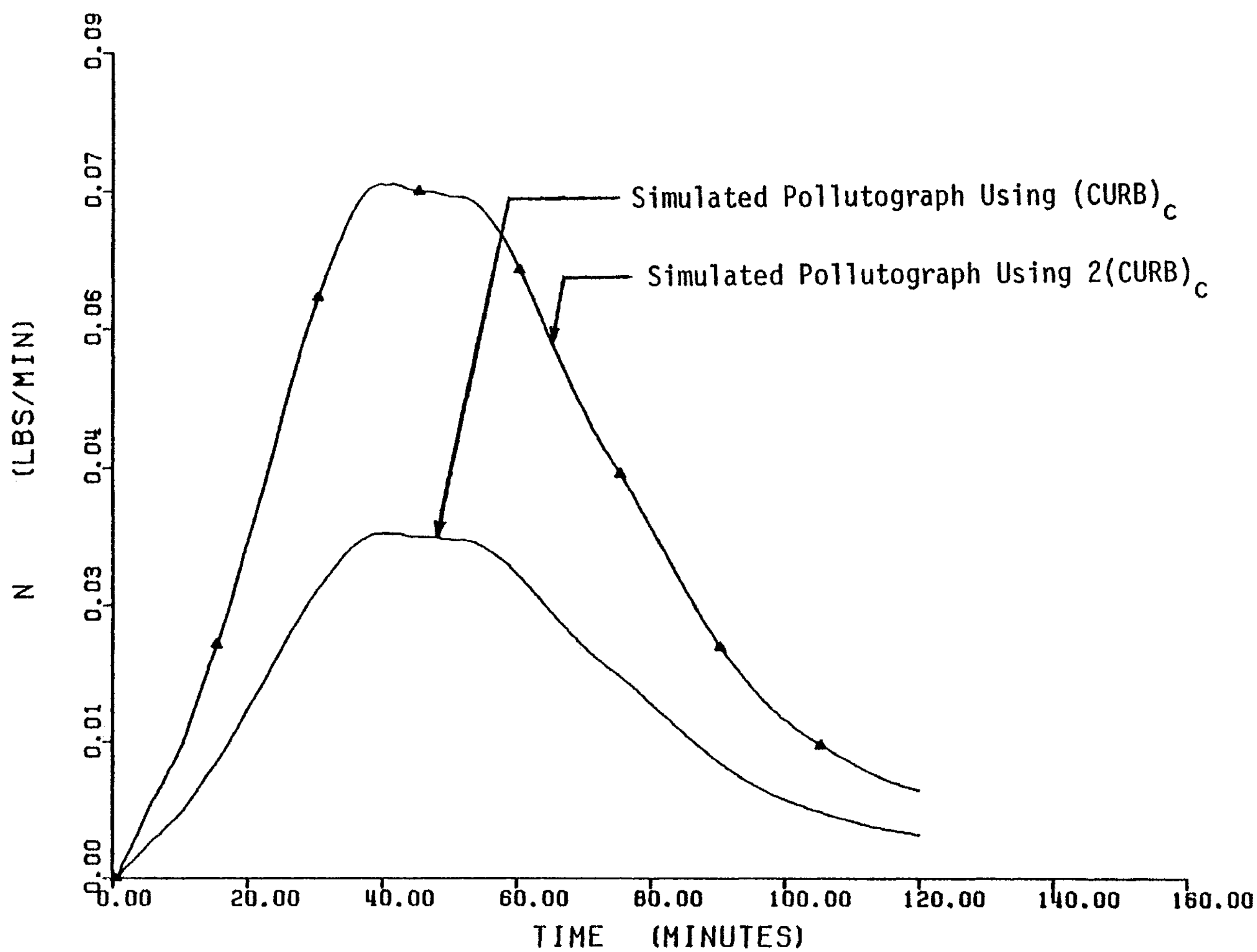


Figure 19 Effect of CURB on Nitrogen Pollutograph Simulation

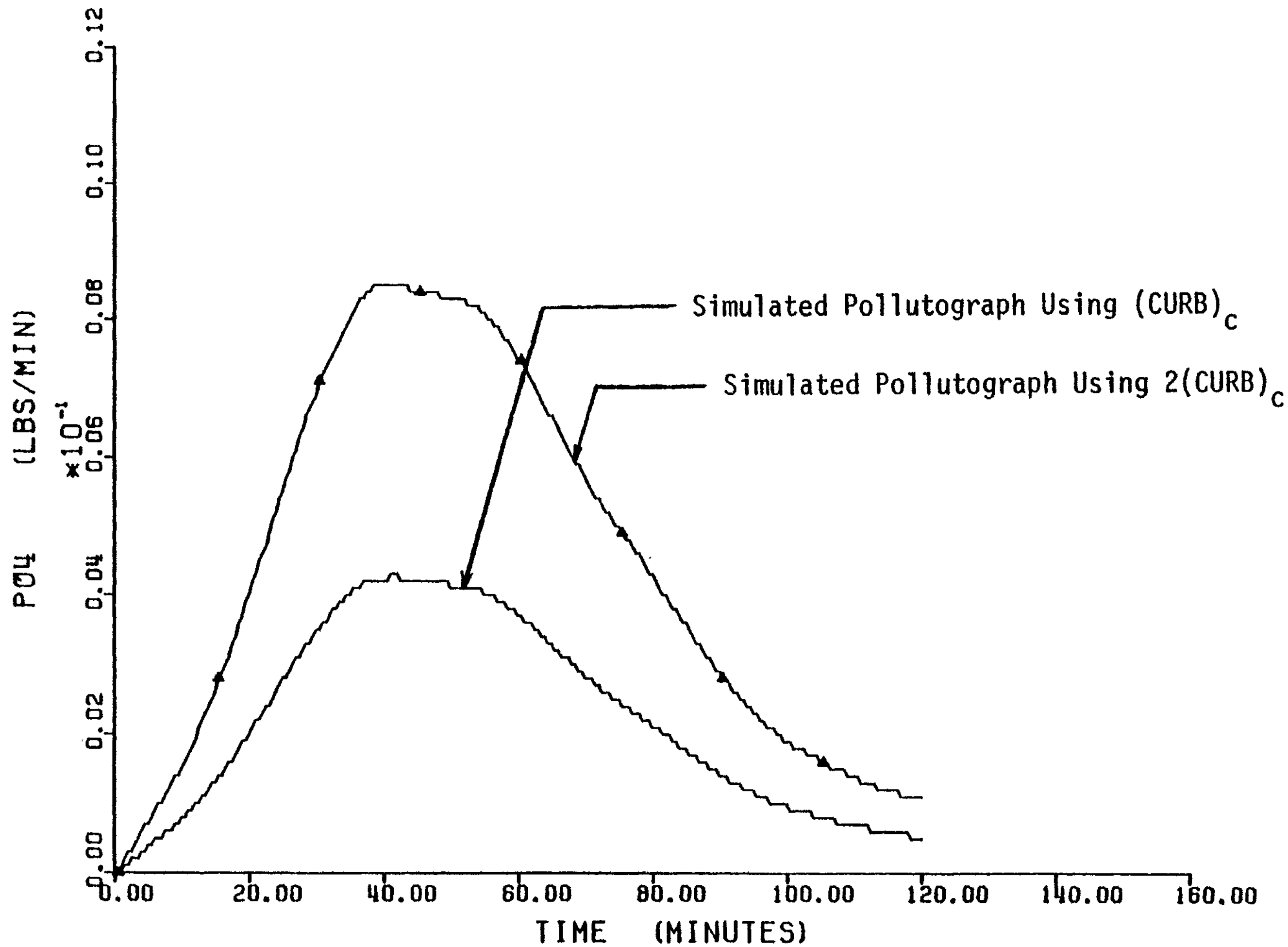


Figure 20 Effect of CURB on Phosphate Pollutograph Simulation

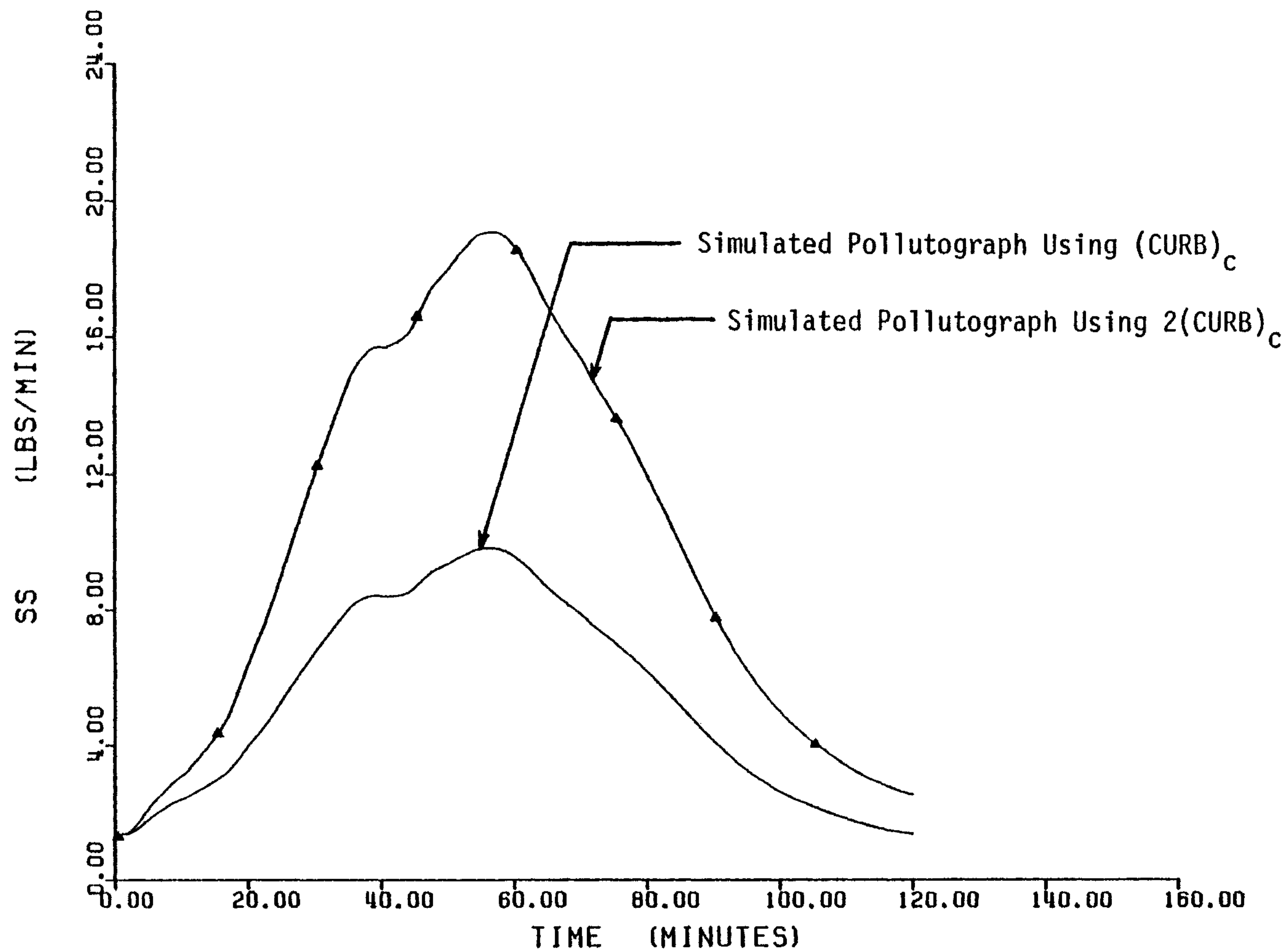


Figure 21 Effect of CURB on Suspended Solids Pollutograph Simulation

words, the greater the K value, the more pronounced the initial flushing effect on a drainage area. This effect is clearly shown in Figures 22 and 26. It is noted that the effect of K on the suspended solids pollutograph response, shown in Figure 27, does not follow the trend shown in Figures 22 to 26. This is due to the inclusion of the availability factor $\overline{A}$ which influences the effects of the rate constant K in equation (42).

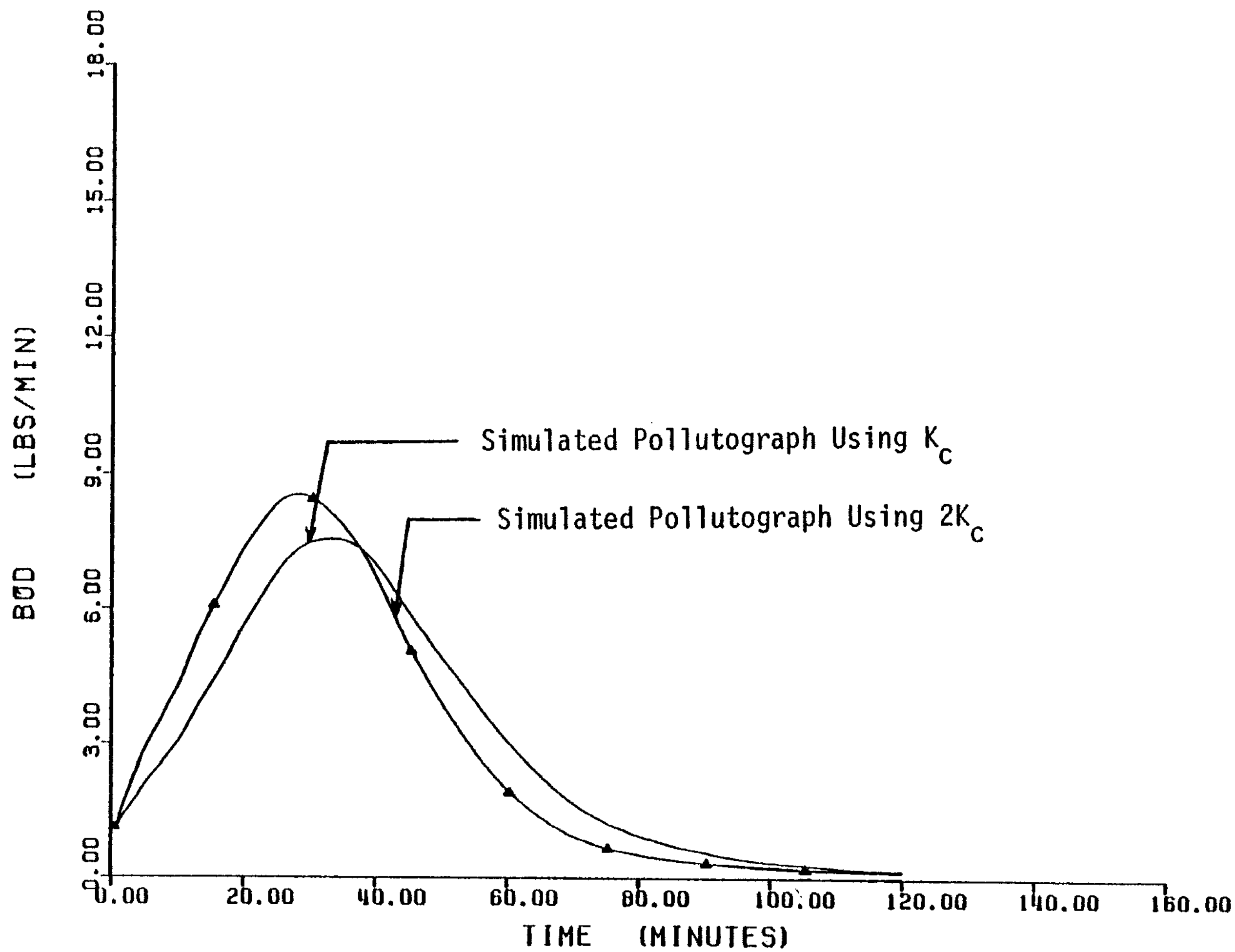


Figure 22 Effect of K on BOD Pollutograph Simulation

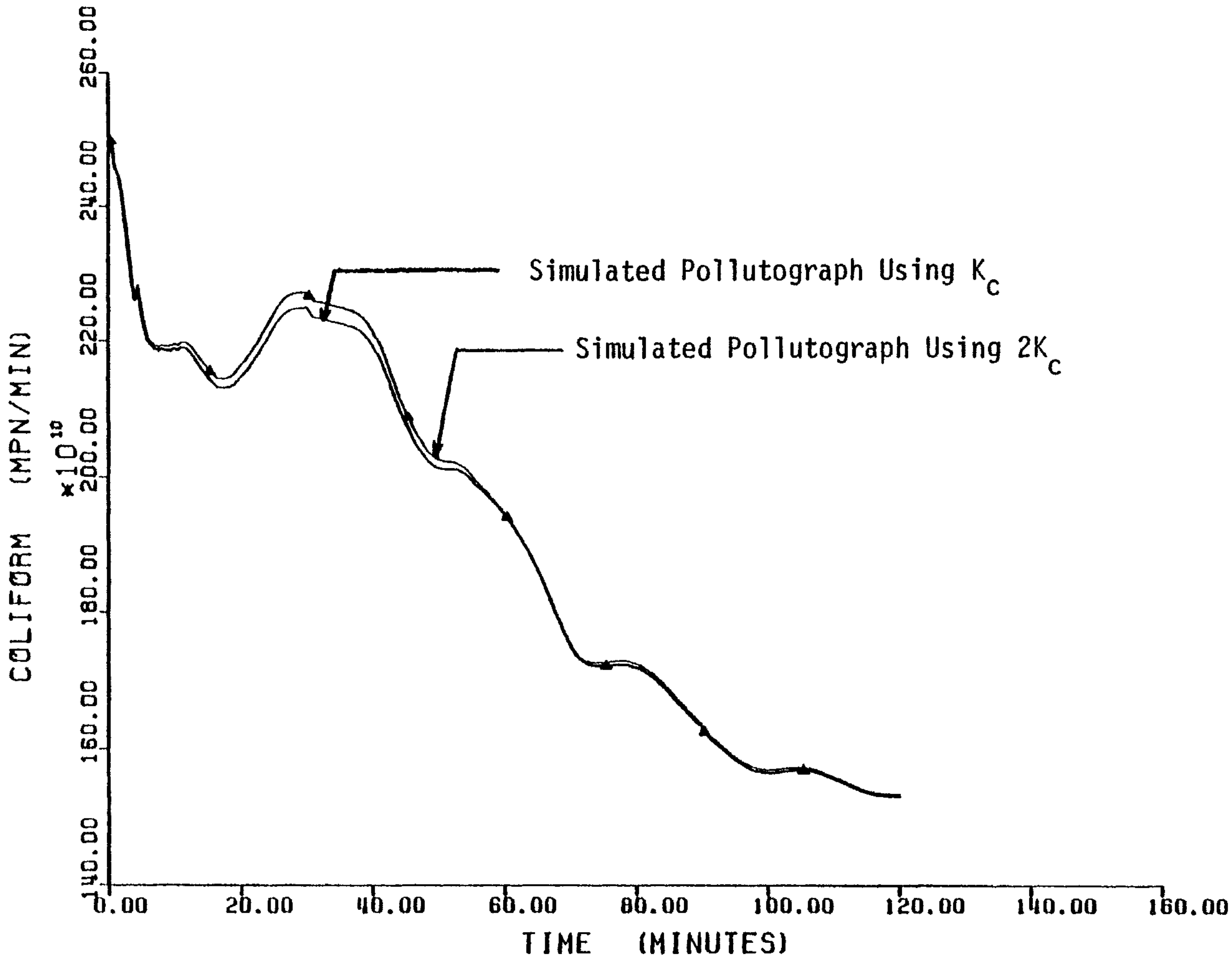


Figure 23 Effect of K on Coliform Pollutograph Simulation

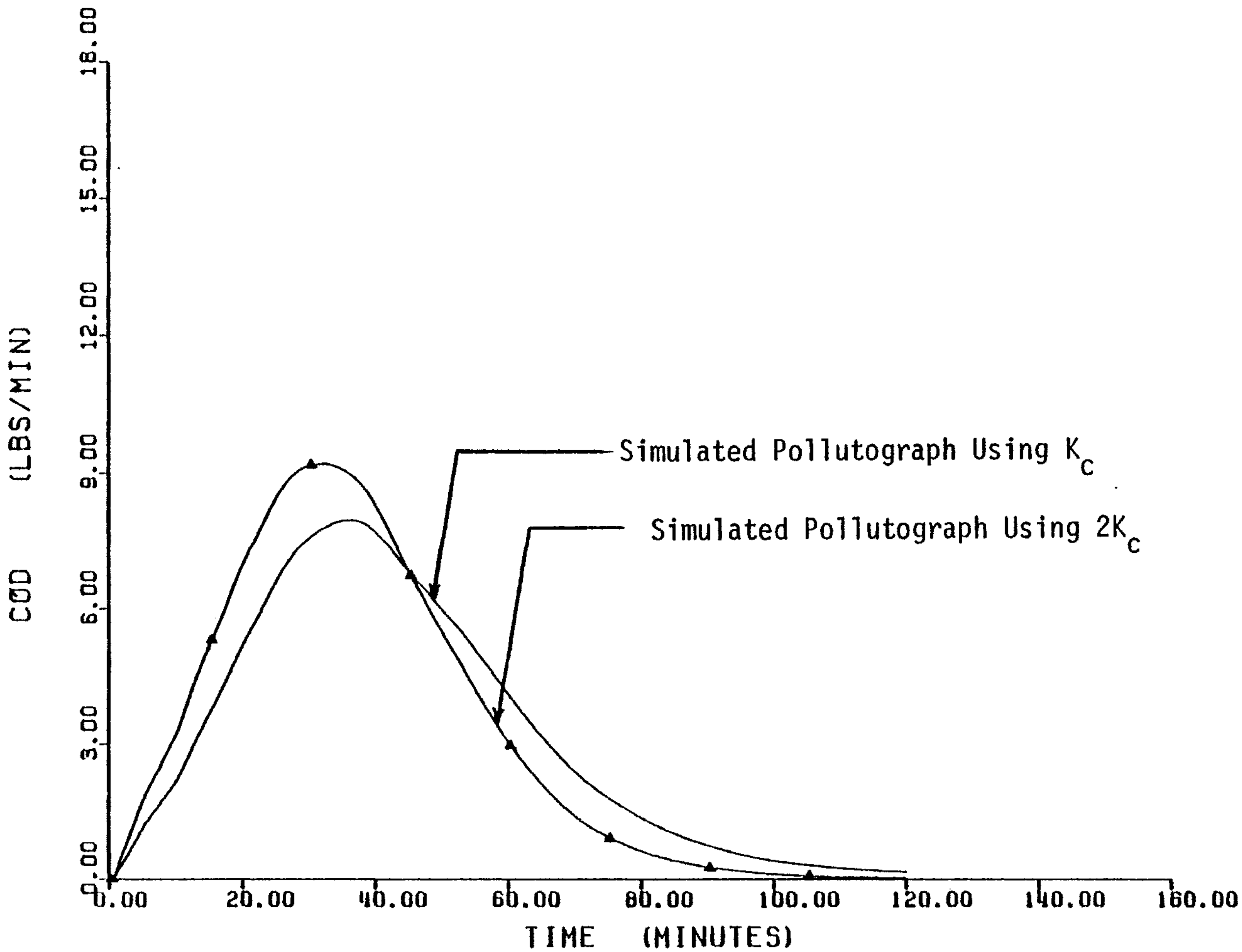


Figure 24 Effect of K on COD Pollutograph Simulation

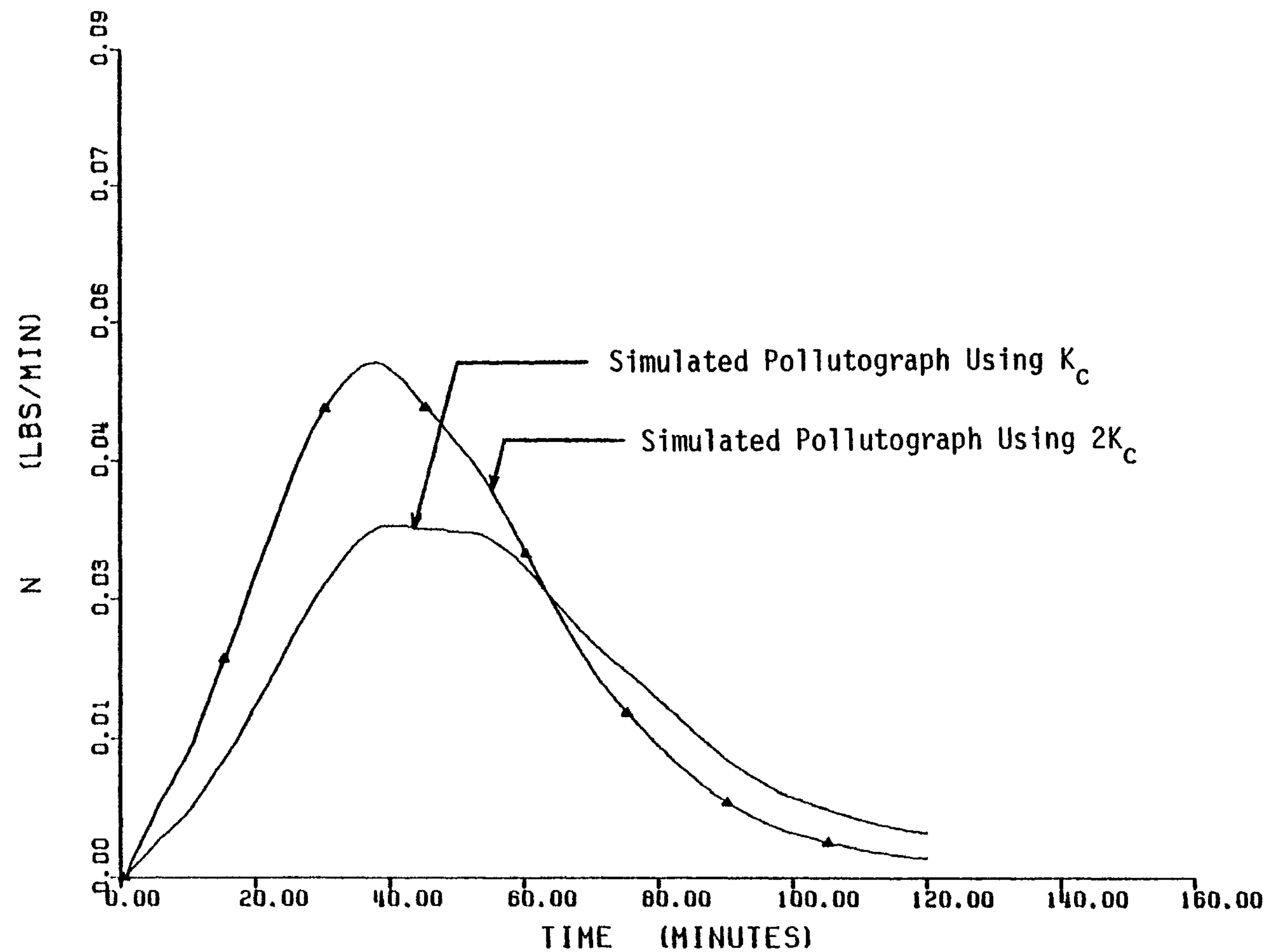


Figure 25 Effect of K on Nitrogen Pollutograph Simulation

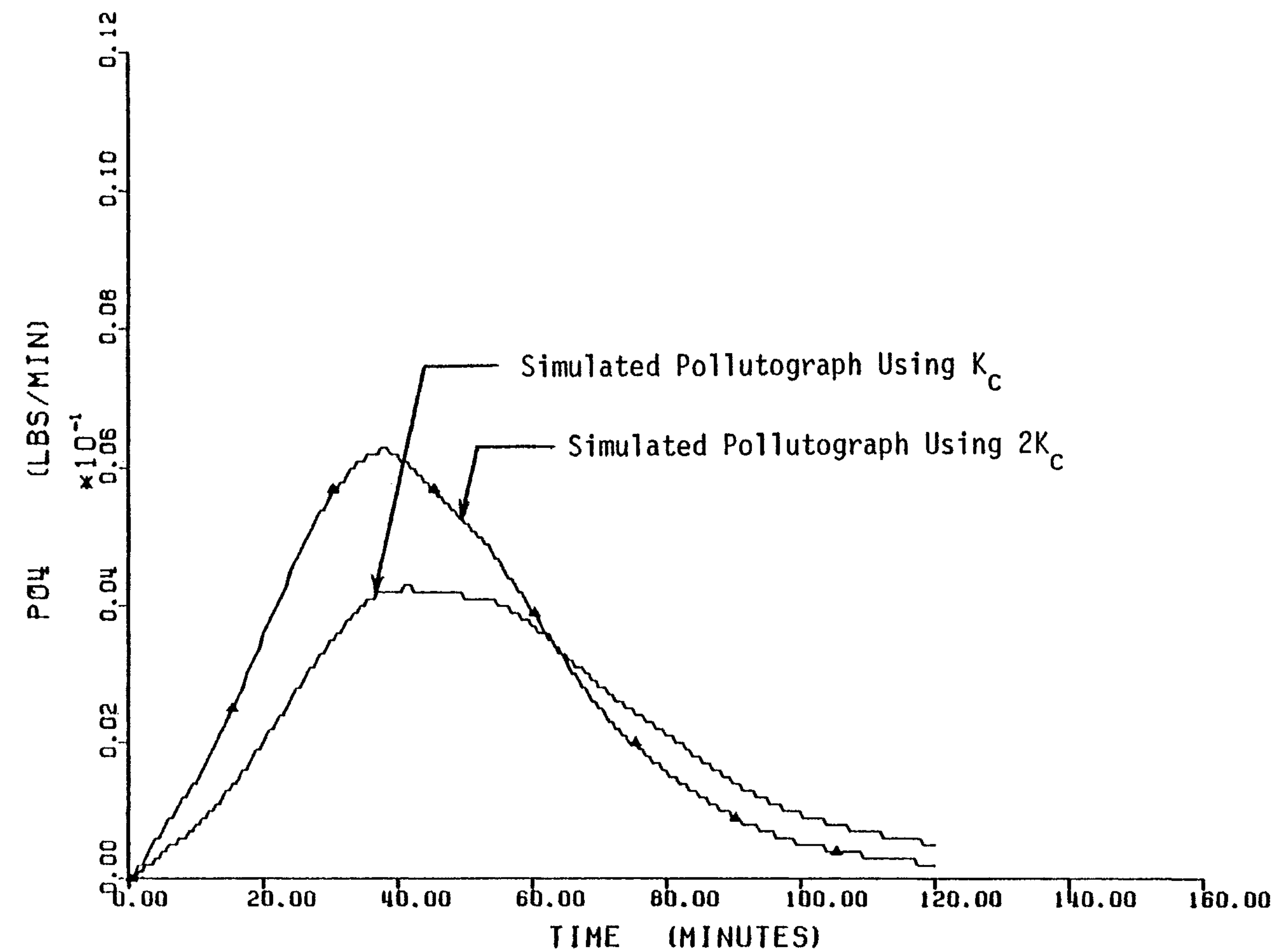


Figure 26 Effect of K on Phosphate Pollutograph Simuation

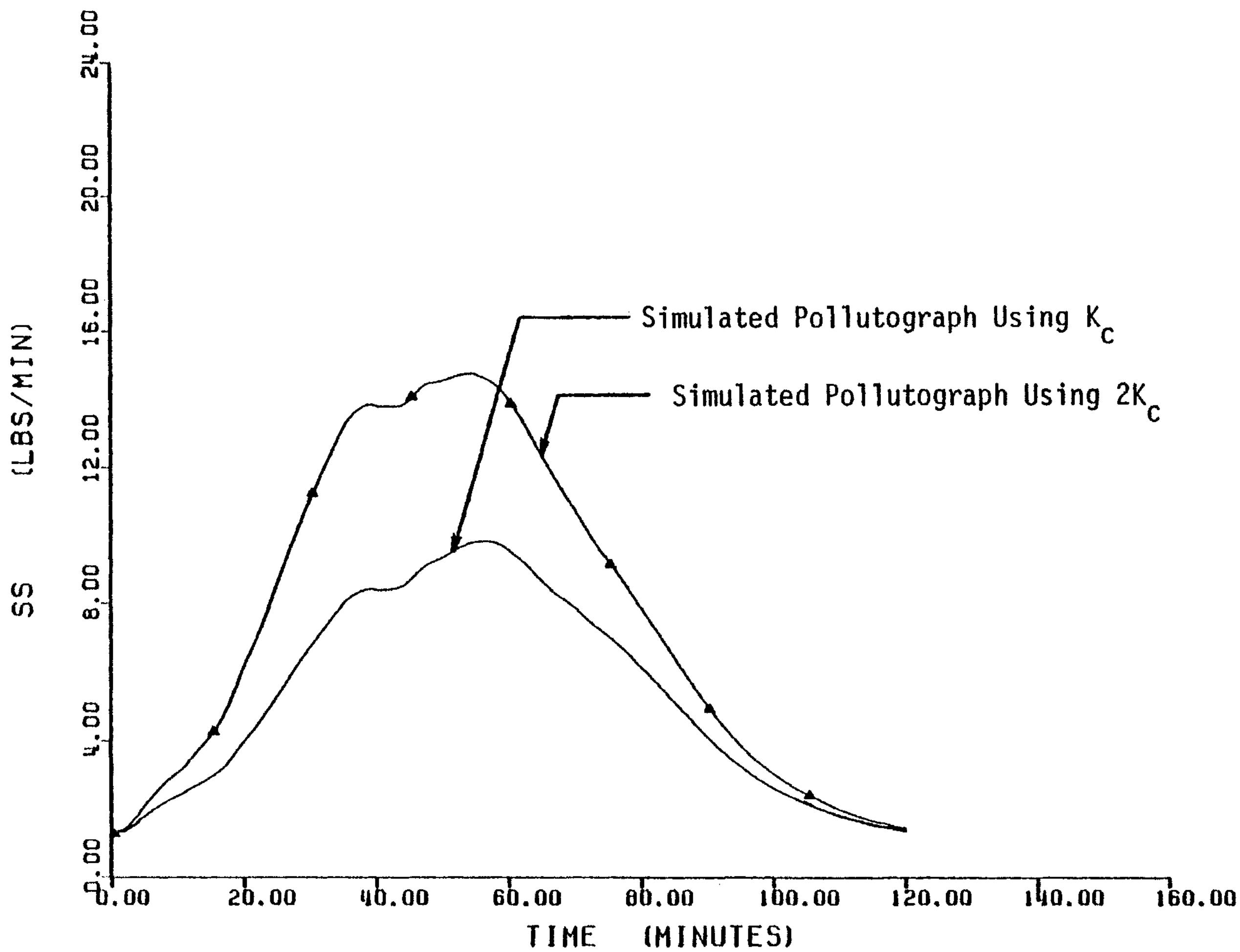


Figure 27 Effect of K on Suspended Solids Pollutograph Simulation

CHAPTER VI

PRESENTATION AND DISCUSSION OF RESULTS

This chapter presents results obtained from two typical urban drainage areas with measured quantity and quality data corresponding to various gaged storm events.

The first drainage area selected is the Oakdale Avenue Basin located in a residential section about six miles northwest of downtown Chicago, Illinois. A generalized map of the catchment is shown in Figure 28. The 12.9 acre basin is composed of 7.05 acres of pervious area and 5.85 acres of impervious area. However, only 5.2 acres of the impervious area are directly connected with a sewer system (38). Due to the small size of the basin, the entire drainage area is treated as a single catchment in the computer simulation instead of being subdivided into individual subcatchments. Therefore, only one inlet located near the downstream boundary of the basin is considered. The estimated impervious area overland length is 25 feet with a slope of 2% and Manning's N of 0.013. The pervious area overland length is 100 feet with a slope of 1% and Manning's N of 0.35. In order to use the MLSURM model, the surface runoff is assumed to be carried through the gutters along Oakdale Avenue. These gutters have a 1% longitudinal slope, 2% side slopes and Manning's N of 0.013.

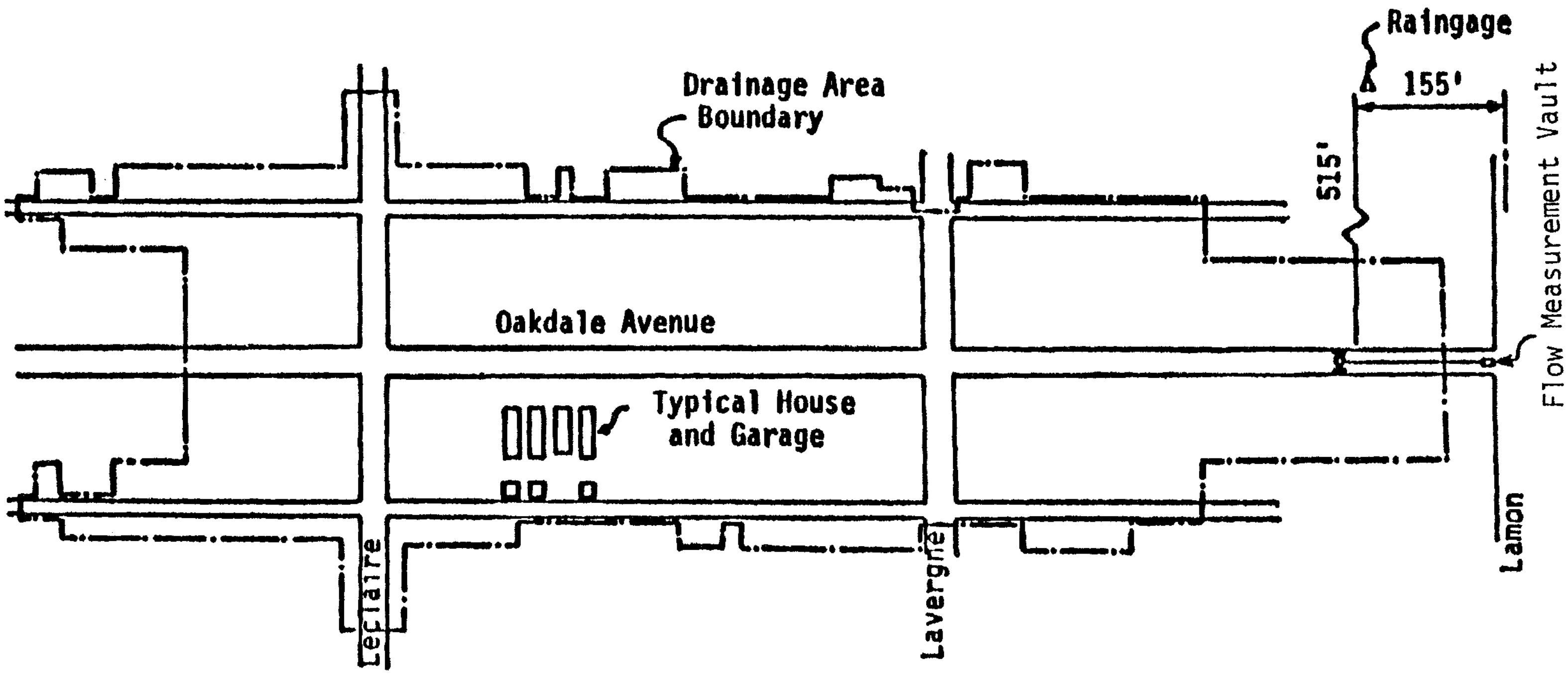


Figure 28 General Plan of Oakdale Avenue Basin, Chicago (38)

A 30-inch diameter sewer transports the flow from the inlet to the flow measurement vault. This pipe has a length of 180 feet with a slope of 0.3% and a Manning's N of 0.013. In this set up the flow is measured in the vault while a rooftop tipping bucket raingage approximately 500 feet from the basin records the rainfall data. Rainfall and runoff have been recorded since 1959 by the City of Chicago's Bureau of Engineering (42).

Two storms were selected to simulate runoff hydrographs, the storm of July 2, 1960, having a duration of 66 minutes and the storm of July 7, 1964, having a duration of 86 minutes. In this application only the quantity simulation is performed by the model because no information concerning runoff quality is available.

For the simulation of the storm of July 2, 1960, surface is assumed to be saturated due to an antecedent storm. Hence, a value of 1 is assigned for the input parameter NCHEX, and a time of 150 minutes input for the parameter AROC. This results in runoff coefficients 0.95 for impervious area, and 0.36 for pervious area during the storm period. The simulated hydrographs by the MLSURM model, the Cincinnati Urban Runoff Model (CURM), the Road Research Laboratory Method (RRL) together with the recorded hydrograph and the corresponding hyetographs are shown in Figure 29.

For the simulation of the storm of July 7, 1964, Hoad's variational runoff coefficients are applied during the storm period. The simulated results are shown in Figure 30.

In comparing the simulated hydrographs to the recorded hydrographs, the time to peaks and the peak discharges from the MLSURM

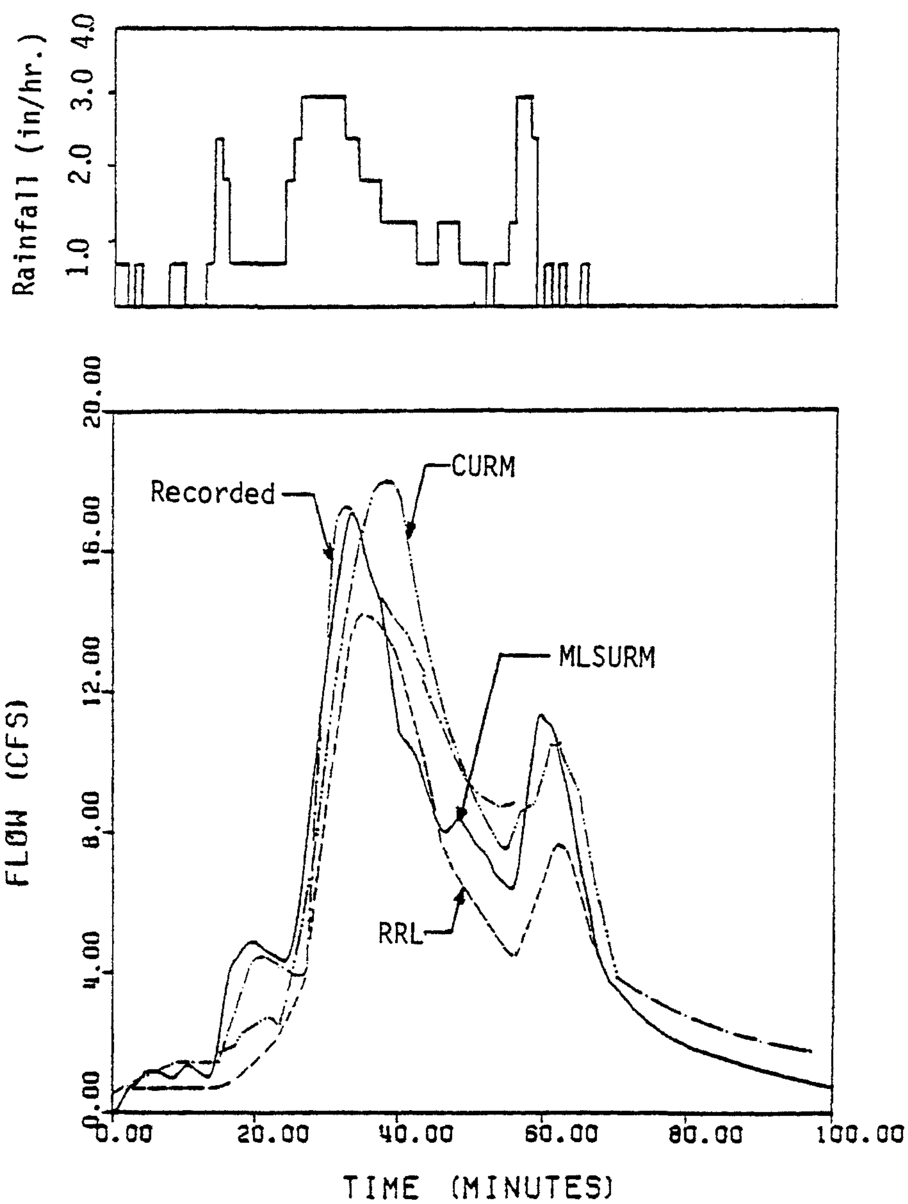


Figure 29 Results from Oakdale Avenue Basin, Chicago Storm of July 2, 1960 (38)

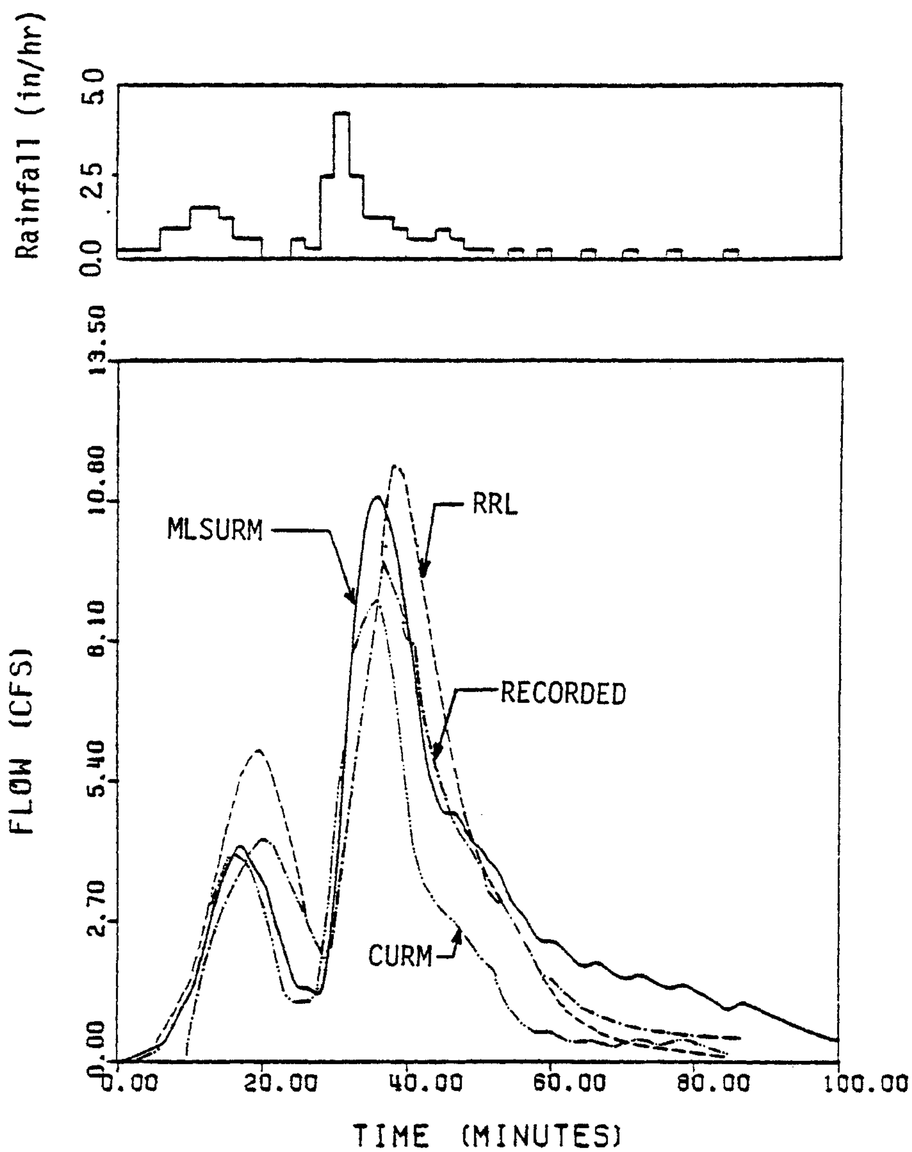


Figure 30 Results from Oakdale Avenue Basin, Chicago Storm of July 7, 1974 (38)

model yielded good agreement. Table V summarizes the magnitude of recorded and simulated peak discharge and time to peak for each storm.

The second application of the model is the Mortimer Avenue Basin in Toronto, Canada. The basin is located about four miles to the northeast of downtown Toronto in the Borough of East York. The total population within the 383 acre catchment is estimated to be approximately 14,600. The predominant land use is single family residential (89.1%), followed by institutional (5.7%), parks and open lands (4.2%) and commercial (1.0%). The catchment has been subdivided into 33 subcatchments ranging in size from 3.9 to 25.9 acres (33). A schematic drainage map of the basin is shown in Figure 31.

The physical characteristics of the subcatchment areas are presented in Table VI. The gutter data and the sewer data are shown in Table VII and Table VIII, respectively. Additional subcatchment data necessary for the quality simulation such as land use types, curb length, and catch basin characteristics are given in Table IX.

A field study by M. M. Dillon Limited Consulting Engineers (33) generated gaged rainfall data and runoff data for this basin. Most of the storm events were monitored in 1976. The runoff hydrograph, the concentration pollutograph of suspended solids and level of BOD were determined. However, no precise information about the amount of pollutant accumulated on the surface prior to a storm was available. Therefore, it is necessary to calibrate the model parameters such as accumulation rates of the dust and dirt, pollutant content of the dust and dirt, and the pollutant removal rate constant K. The

TABLE V Comparison of Storm Peaks, Oakdale Avenue Basin (38)

Storm	Peak	Peak Discharges, cfs				Time to Peak, Minutes			
Date	No.	Recorded	MLSURM	CURM	RRL	Recorded	MLSURM	CURM	RRL
7/02/60	1	17.40	16.99	18.13	14.30	32	34	38	38
	2	Not recorded	11.35	10.58	6.90	Not recorded	60	62	62
7/07/64	1	4.20	4.15	3.95	6.00	20	17	17	20
	2	9.60	10.91	8.83	11.40	37	36	36	39

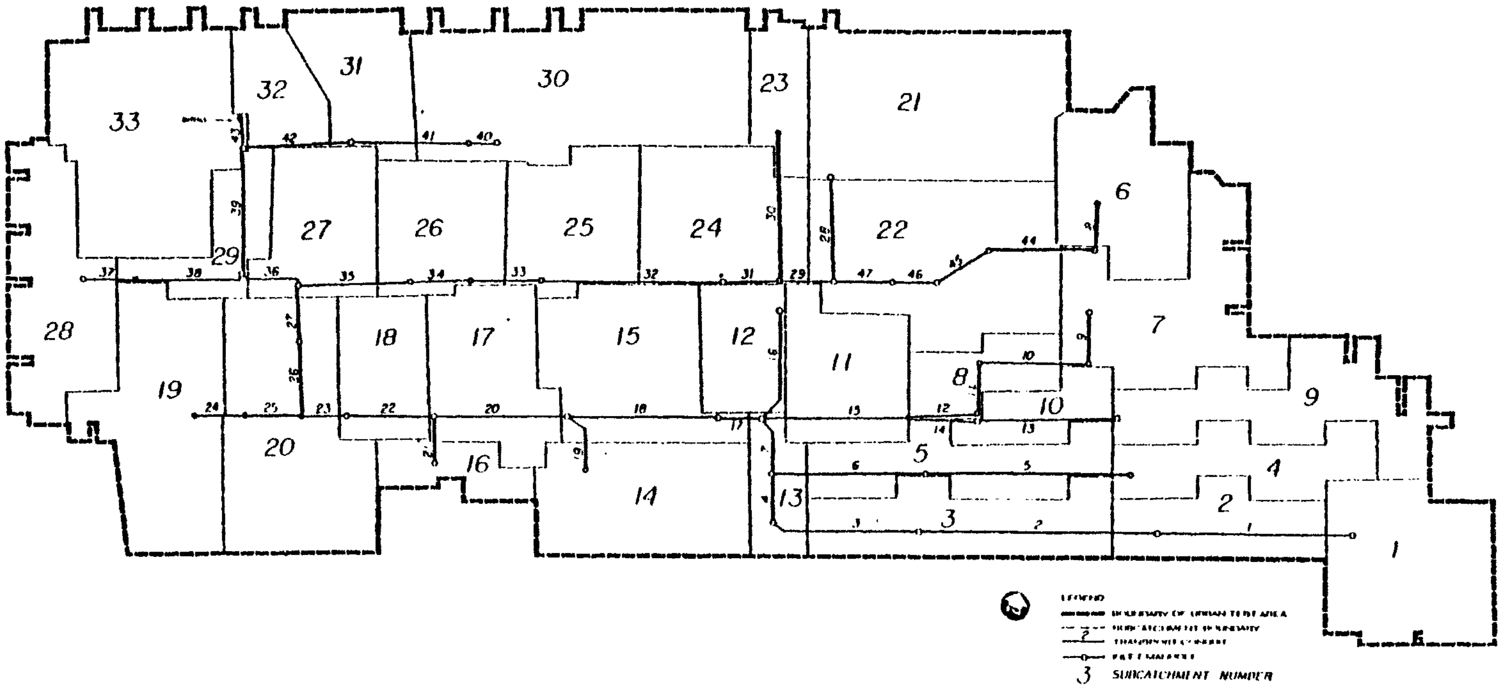


Figure 31 Schematic Map of Mortimer Avenue Basin, Toronto, Canada (33)

Table VI Subcatchment Data, Mortimer Avenue Basin, Toronto, Canada

SUBCATCH-MENT NO.	COLLECTING SEWER NO.	AREA (AC)	FRACTION IMPERV.	IMPERVIOUS AREA LENGTH (FT)	IMPERVIOUS AREA SLOPE (FT/FT)	IMPERVIOUS AREA MANNING'S N	PERVIOUS AREA LENGTH (FT)	PERVIOUS AREA SLOPE (FT/FT)	PERVIOUS AREA MANNING'S N
1	1	14.200	0.3880	25.00	0.0350	0.0130	120.00	0.0090	0.2500
2	2	7.800	0.3890	25.00	0.0350	0.0130	120.00	0.0070	0.2500
3	3	11.300	0.3900	25.00	0.0350	0.0130	120.00	0.0190	0.2500
4	5	8.700	0.3760	25.00	0.0350	0.0130	120.00	0.0090	0.2500
5	6	9.700	0.4140	25.00	0.0350	0.0130	120.00	0.0130	0.2500
6	8	11.700	0.2420	25.00	0.0350	0.0130	120.00	0.0100	0.2500
7	9	16.200	0.3300	25.00	0.0350	0.0130	120.00	0.0150	0.2500
8	15	5.600	0.3760	25.00	0.0350	0.0130	120.00	0.0040	0.2500
9	13	13.600	0.4220	25.00	0.0350	0.0130	120.00	0.0080	0.2500
10	14	4.400	0.4130	25.00	0.0350	0.0130	120.00	0.0070	0.2500
11	15	10.000	0.6240	25.00	0.0350	0.0130	360.00	0.0170	0.2500
12	16	6.400	0.4940	25.00	0.0350	0.0130	200.00	0.0170	0.2500
13	17	4.300	0.5640	25.00	0.0350	0.0130	120.00	0.0100	0.2500
14	19	13.800	0.4930	25.00	0.0350	0.0130	120.00	0.0140	0.2500
15	20	15.300	0.3710	25.00	0.0350	0.0130	120.00	0.0090	0.2500
16	21	3.900	0.4390	25.00	0.0350	0.0130	120.00	0.0190	0.2500
17	22	11.500	0.5670	25.00	0.0350	0.0130	120.00	0.0150	0.2500
18	23	8.300	0.4060	25.00	0.0350	0.0130	120.00	0.0180	0.2500
19	24	16.600	0.3940	25.00	0.0350	0.0130	120.00	0.0100	0.2500
20	27	18.600	0.3850	25.00	0.0350	0.0130	120.00	0.0080	0.2500
21	28	22.100	0.3720	25.00	0.0350	0.0130	120.00	0.0140	0.2500
22	29	22.100	0.3760	25.00	0.0350	0.0130	120.00	0.0060	0.2500
23	30	4.400	0.5770	25.00	0.0350	0.0130	120.00	0.0090	0.2500
24	32	12.900	0.3120	25.00	0.0350	0.0130	250.00	0.0130	0.2500
25	33	10.500	0.3210	25.00	0.0350	0.0130	120.00	0.0090	0.2500
26	35	10.600	0.4400	25.00	0.0350	0.0130	120.00	0.0090	0.2500
27	36	10.000	0.3950	25.00	0.0350	0.0130	120.00	0.0100	0.2500
28	37	12.900	0.3920	25.00	0.0350	0.0130	120.00	0.0050	0.2500
29	39	5.000	0.4750	25.00	0.0350	0.0130	120.00	0.0040	0.2500
30	40	25.900	0.3250	25.00	0.0350	0.0130	120.00	0.0110	0.2500
31	42	7.700	0.0480	25.00	0.0350	0.0130	120.00	0.0070	0.2500
32	43	5.400	0.3470	25.00	0.0350	0.0130	120.00	0.0090	0.2500
33	43	20.900	0.4240	25.00	0.0350	0.0130	120.00	0.0040	0.2500

Table VII Gutter Data, Mortimer Avenue Basin, Toronto, Canada

SUBCATCH-MENT NO.	NO. OF GUTTERS	AVG. LENGTH (FT)	AVG. SLOPE (FT/FT)	MANNING'S N	SIDE SLOPE (FT/FT)
1	8	700.00	0.0070	0.0130	0.0350
2	2	850.00	0.0140	0.0130	0.0350
3	2	1200.00	0.0120	0.0130	0.0350
4	1	1120.00	0.0063	0.0130	0.0350
5	1	1350.00	0.0051	0.0130	0.0350
6	2	500.00	0.0140	0.0130	0.0350
7	3	600.00	0.0103	0.0130	0.0350
8	2	400.00	0.0050	0.0130	0.0350
9	1	950.00	0.0070	0.0130	0.0350
10	2	500.00	0.0050	0.0130	0.0350
11	1	800.00	0.0200	0.0130	0.0350
12	1	600.00	0.0150	0.0130	0.0350
13	2	650.00	0.0035	0.0130	0.0350
14	4	800.00	0.0100	0.0130	0.0350
15	7	720.00	0.0074	0.0130	0.0350
16	4	313.00	0.0140	0.0130	0.0350
17	5	720.00	0.0110	0.0130	0.0350
18	4	650.00	0.0170	0.0130	0.0350
19	8	740.00	0.0110	0.0130	0.0350
20	8	690.00	0.0063	0.0130	0.0350
21	5	1120.00	0.0044	0.0130	0.0350
22	10	438.00	0.0080	0.0130	0.0350
23	2	650.00	0.0070	0.0130	0.0350
24	2	940.00	0.0100	0.0130	0.0350
25	4	650.00	0.0100	0.0130	0.0350
26	4	650.00	0.0070	0.0130	0.0350
27	4	650.00	0.0100	0.0130	0.0350
28	6	520.00	0.0100	0.0130	0.0350
29	4	920.00	0.0120	0.0130	0.0350
30	12	680.00	0.0100	0.0130	0.0350
31	1	440.00	0.0150	0.0130	0.0350
32	2	635.00	0.0100	0.0130	0.0350
33	10	880.00	0.0100	0.0130	0.0350

Table VIII Sewer Data, Mortimer Avenue Basin, Toronto, Canada

SEWER NO.	DOWNSTREAM SEWER NO.	LENGTH (FT)	SLOPE (%)	MANNING'S N	DIAMETER (FT)
1	2	999.00	0.47	0.0130	2.00
2	3	1221.00	0.73	0.0130	2.00
3	4	769.00	0.37	0.0130	2.50
4	7	240.00	0.40	0.0130	3.00
5	6	934.00	0.40	0.0130	1.80
6	7	750.00	1.40	0.0130	1.50
7	17	299.00	0.54	0.0130	3.00
9	10	270.00	0.27	0.0130	2.00
10	11	560.00	0.28	0.0130	2.25
11	12	264.00	0.62	0.0130	2.00
12	15	343.00	1.35	0.0130	2.00
13	14	566.00	0.27	0.0130	2.50
14	15	346.00	0.57	0.0130	2.50
15	17	734.00	1.96	0.0130	2.50
16	17	300.00	3.07	0.0130	1.00
17	18	221.00	0.67	0.0130	3.75
18	20	765.00	0.83	0.0130	4.00
19	20	239.00	0.33	0.0130	2.00
20	22	700.00	0.26	0.0130	5.00
21	22	237.00	0.41	0.0130	1.25
22	23	451.00	0.38	0.0130	5.00
23	26	212.00	0.49	0.0130	5.00
24	25	256.00	1.40	0.0130	1.75
25	26	285.00	1.30	0.0130	2.00
26	27	380.00	0.49	0.0150	5.00
27	36	270.00	0.80	0.0150	5.00
8	44	335.00	0.84	0.0130	1.00
44	45	464.00	1.30	0.0130	1.00
45	46	322.00	0.80	0.0130	1.00
46	47	157.00	0.80	0.0130	1.50
47	29	267.00	0.50	0.0130	1.75
28	29	510.00	0.85	0.0130	2.25
29	31	268.00	0.76	0.0130	2.50
30	31	641.00	0.50	0.0130	1.25
31	32	285.00	0.50	0.0130	3.00
32	33	950.00	0.50	0.0130	3.25
33	34	325.00	0.50	0.0130	3.25
34	35	348.00	0.52	0.0130	3.25
35	36	532.00	0.52	0.0130	3.25
36	39	320.00	0.53	0.0150	5.50
37	38	253.00	0.37	0.0130	2.00
38	39	557.00	0.25	0.0130	2.25
39	43	630.00	0.53	0.0150	5.50
40	41	163.00	0.75	0.0130	2.00
41	42	615.00	0.41	0.0130	2.00
42	43	551.00	0.46	0.0130	2.00
43	0	100.00	0.78	0.0150	5.50

TABLE IX Land Use Data, Mortimer Avenue Basin, Toronto, Canada

Subcatchment No.	Land Use	Curb Length (100 feet)	Catch Basin Volume (ft^3)	Catch Basin BOD (MG/L)
1	1	52.4	13.0	100.0
2	1	28.6	13.0	100.0
3	1	45.0	13.0	100.0
4	1	31.9	13.0	100.0
5	1	39.6	13.0	100.0
6	1	45.4	13.0	100.0
7	1	70.7	13.0	100.0
8	1	28.3	13.0	100.0
9	1	53.7	13.0	100.0
10	1	18.0	13.0	100.0
11	3	12.7	13.0	100.0
12	3	12.9	13.0	100.0
13	1	22.7	13.0	100.0
14	1	52.0	13.0	100.0
15	1	56.4	13.0	100.0
16	1	17.6	13.0	100.0
17	1	38.2	13.0	100.0
18	1	32.4	13.0	100.0
19	1	66.2	13.0	100.0
20	1	64.1	13.0	100.0
21	1	95.7	13.0	100.0
22	1	80.8	13.0	100.0
23	1	19.7	13.0	100.0
24	5	35.9	13.0	100.0
25	1	38.1	13.0	100.0
26	1	39.7	13.0	100.0
27	1	37.9	13.0	100.0
28	1	46.9	13.0	100.0
29	1	26.9	13.0	100.0
30	1	108.8	13.0	100.0
31	5	10.5	13.0	100.0
32	1	26.9	13.0	100.0
33	1	78.8	13.0	100.0

calibration procedure is basically a trial and error approach to determine the best combination of the parameter values which minimize the differences between simulated pollutographs and recorded pollutographs. Three storms occurring on June 30, July 7, and July 31 of 1976 were selected to calibrate the quality parameters. Table X shows the calibrated parameter values obtained from this calibration process. The simulation results of these storms using calibrated parameter value are shown in Figures 32, 33, 34.

Additional storms were chosen to verify the model using the calibrated parameter values. The simulated results are presented in Figures 35 to 43. As can be seen from these figures, the simulated hydrographs are as close if not closer to the hydrographs generated by the EPA's SWMM. Both the peak discharges and the time synchronization are in good agreement with the recorded hydrographs. In the simulation of pollutograph, it is probably not appropriate to compare the pollutographs obtained by the MLSURM model to those results obtained by the SWMM model because the pollutographs simulated by the SWMM are based on the default parameter values of dust and dirt accumulation rates and pollutant content as shown in Table I and Table II. However, the results obtained using data given in Table X do indicate that considerably improved pollutograph simulation is achieved with proper model calibration. For instance, the simulation results of the storm on July 2, 1976 as shown in Figure 38, the concentration pollutograph of suspended solids obtained by the MLSURM model is closer to the recorded pollutograph. Similar results are observed for the storm of July 11, 1976 as shown in Figure 39, the

TABLE X Calibrated Accumulation Rates of Dust and Dirt, Pollutant Contents in Dust and Dirt, Pollutant Removal Constant K

Land Use	Accumulation Rate of Dust and Dirt (Pounds/Day/100 ft - curb)
Single Family, residential	1.4
Commercial	6.6
Undeveloped or Park	3.0

Land Use	Milligram pollutant/gram Dust and Dirt	
	Suspended Solids	BOD
Single Family, residential	160	35.
Commercial	160	30.8
Undeveloped or Park	160	35.

	Suspended Solids	BOD
Pollutant Removal Constant K	10.	15.

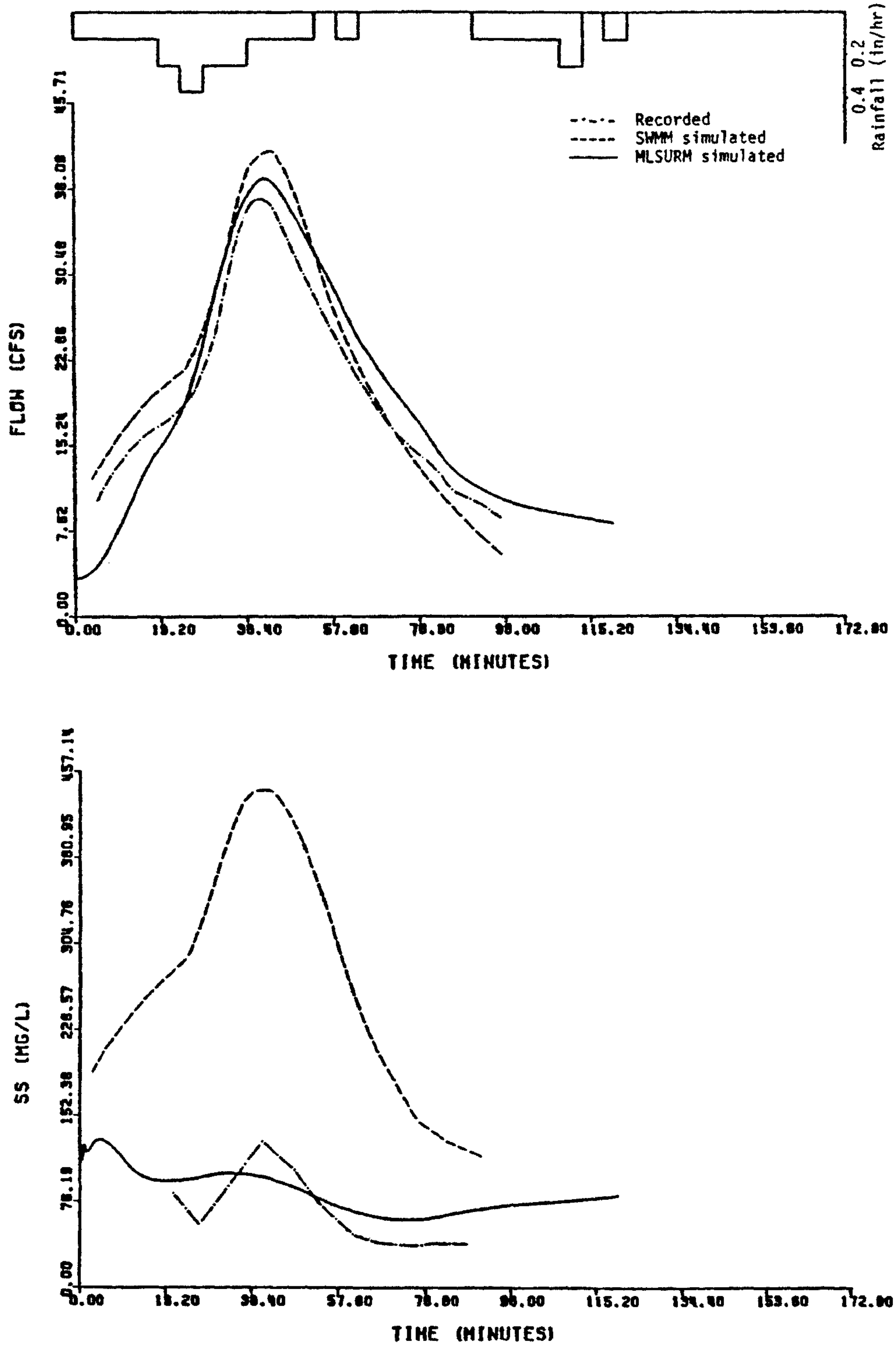


Figure 32 Results from Mortimer Avenue Basin, Toronto, Canada Storm of June 30, 1976 (33)

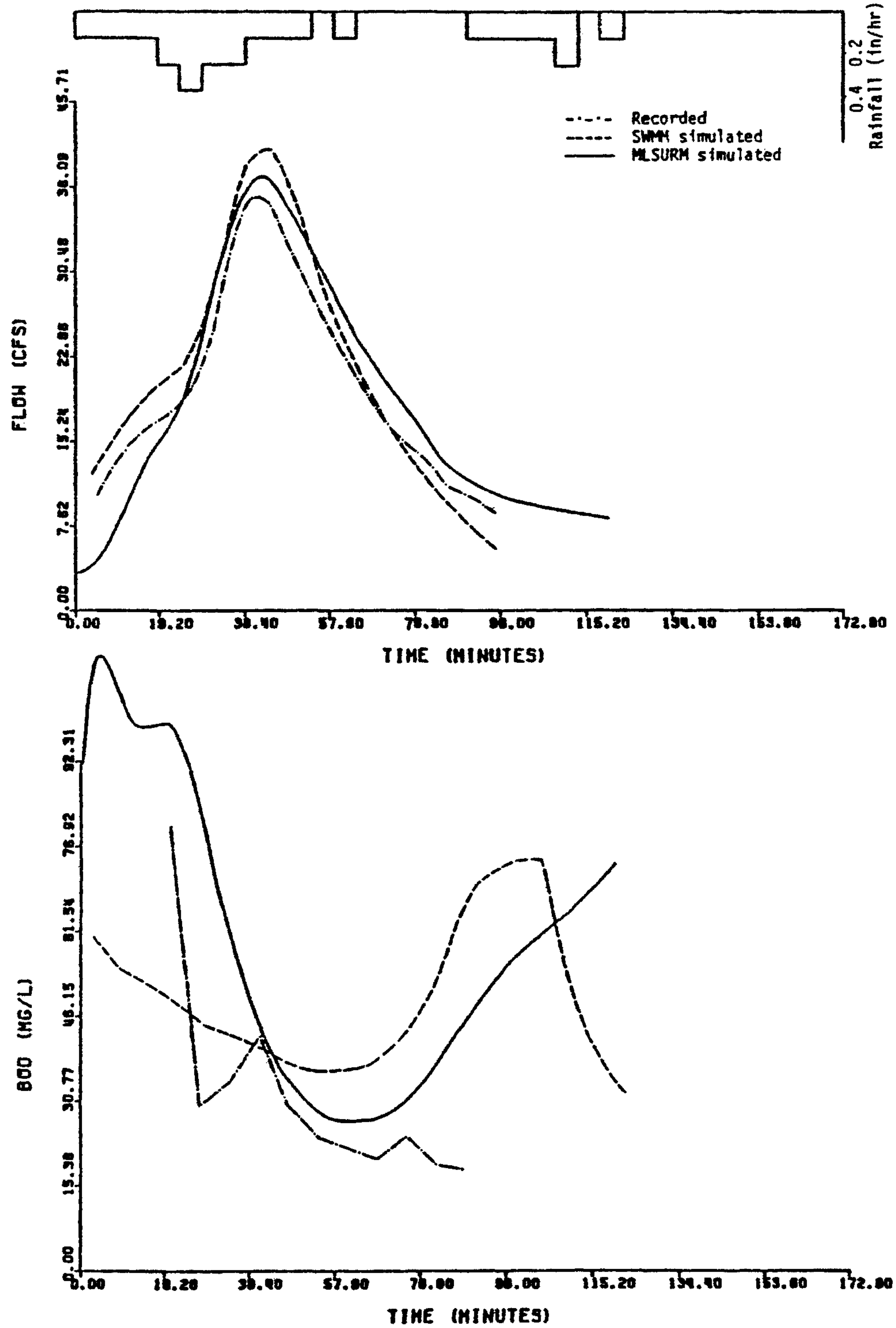


Figure 32 (continued) Results from Mortimer Avenue Basin, Toronto, Canada
Storm of June 30, 1976 (33)

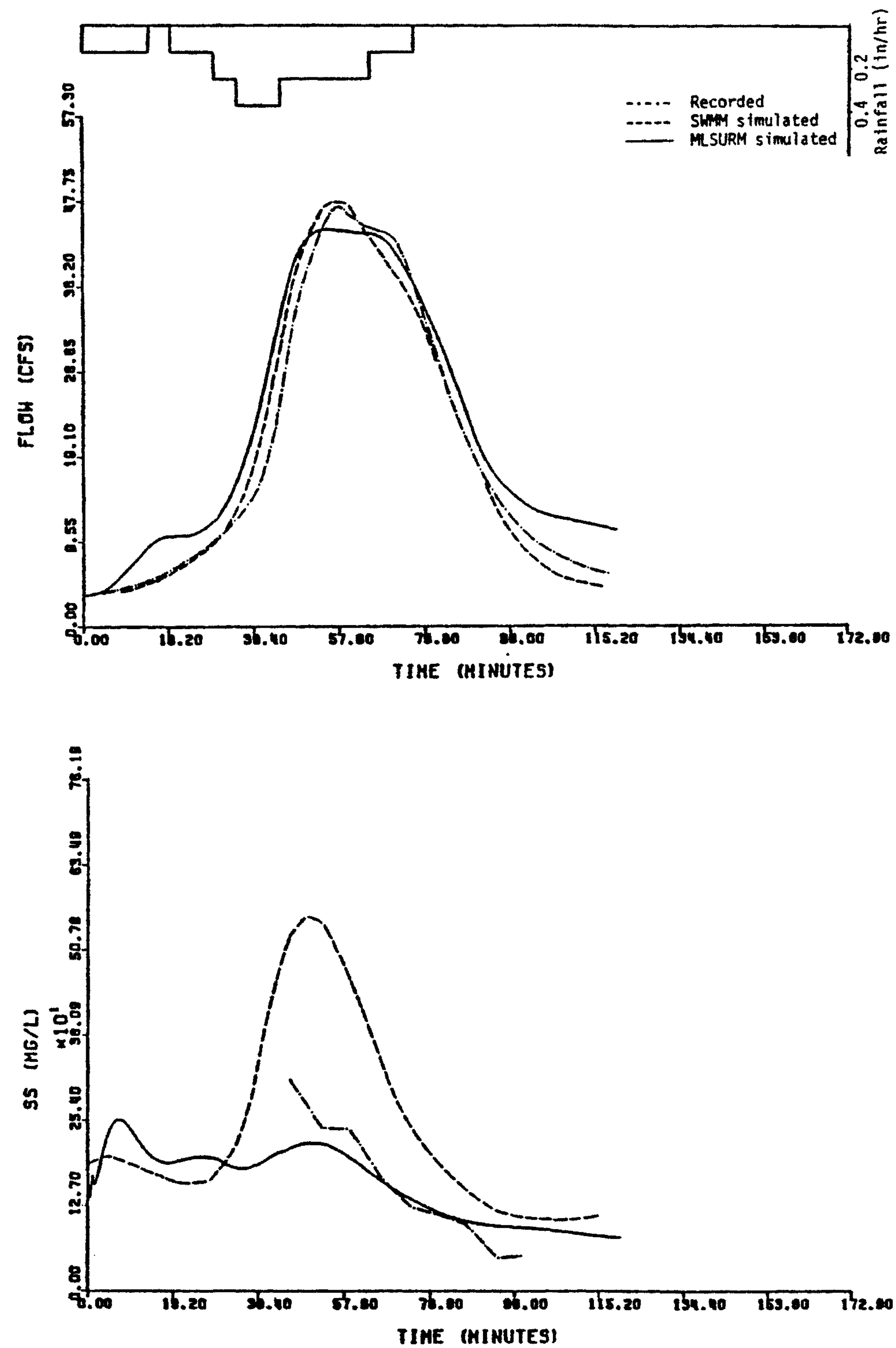


Figure 33 Results from Mortimore Avenue Basin, Toronto, Canada
Storm of July 7, 1976 (33)

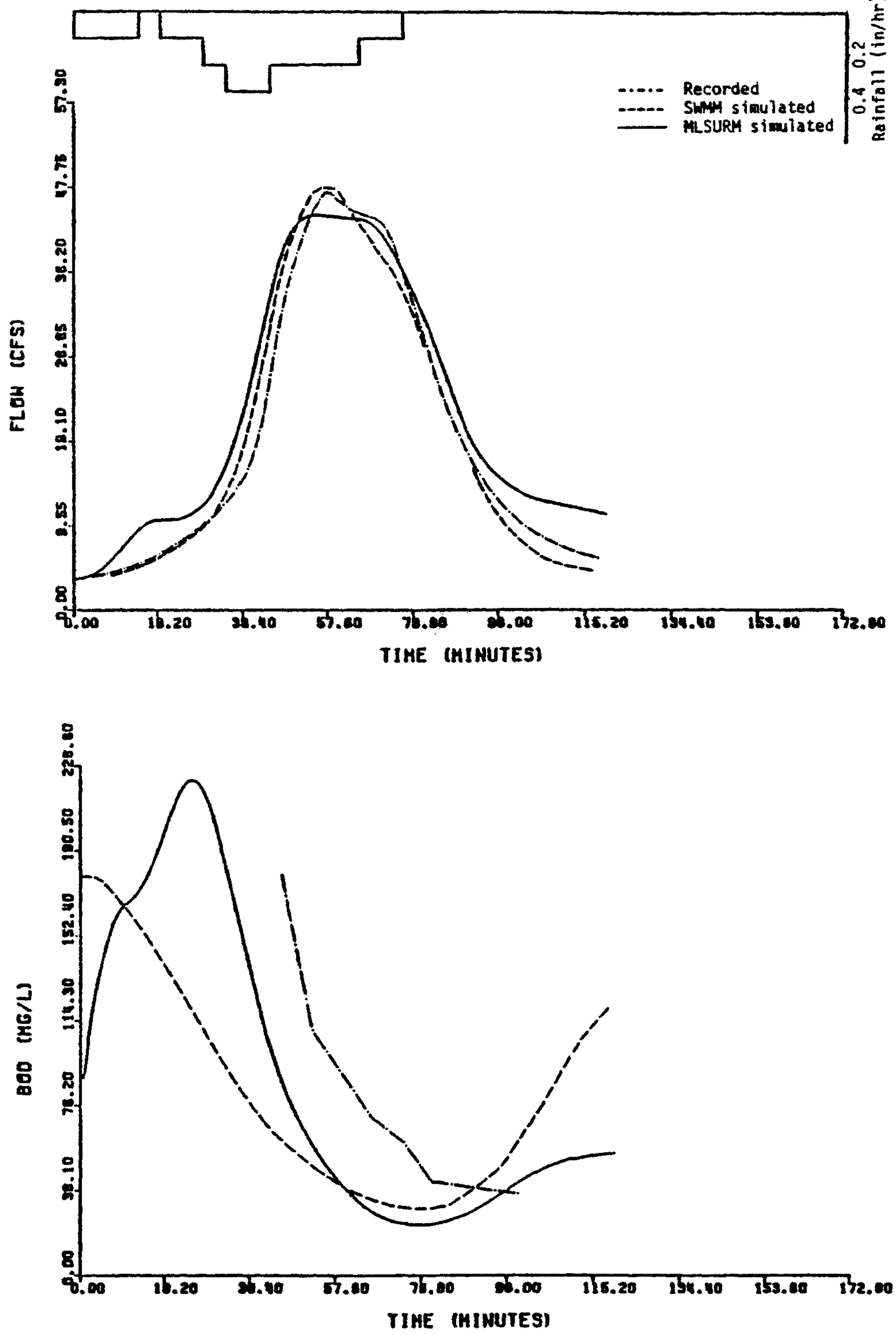


Figure 33 (continued) Results from Mortimer AVenue Basin, Toronoto, Canada
Storm of July 7, 1976 (33).

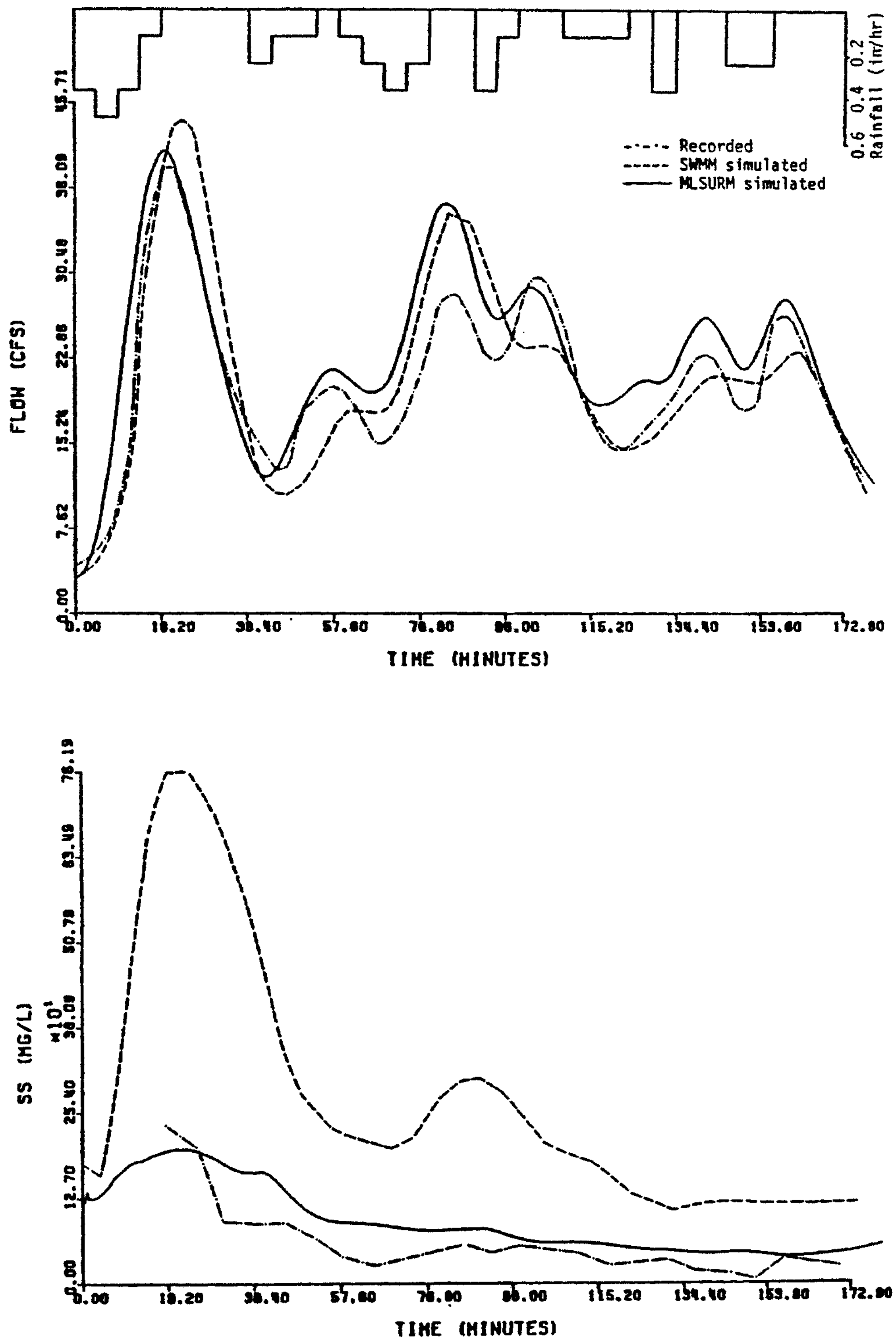


Figure 34 Results from Mortimer Avenue Basin, Toronto, Canada
Storm of July 31, 1976 (33)

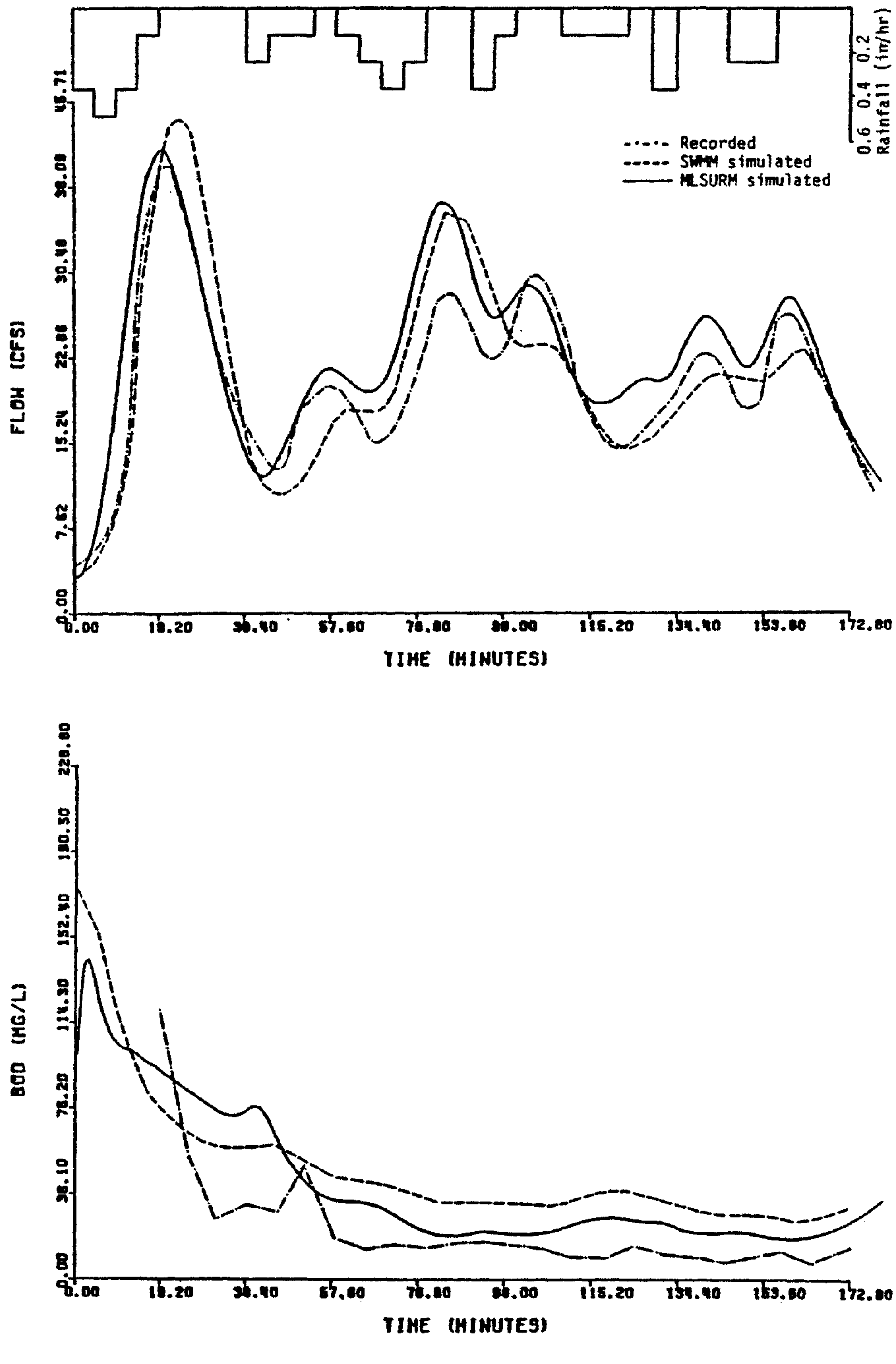


Figure 34 (continued) Results from Mortimer Avenue Basin
Toronto, Canada
Storm of July 31, 1976 (33)

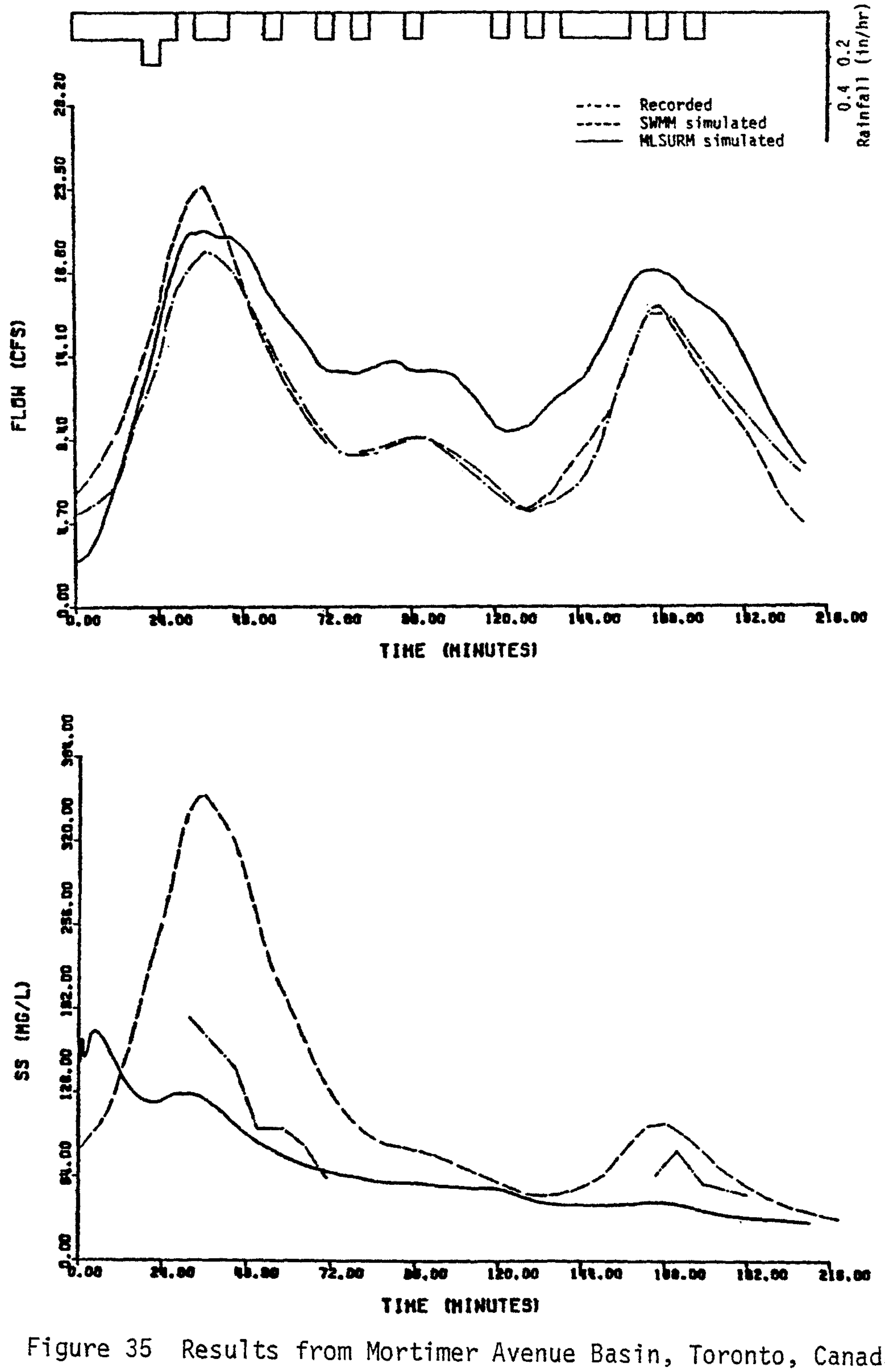


Figure 35 Results from Mortimer Avenue Basin, Toronto, Canada Storm of April 25, 1976 (33)

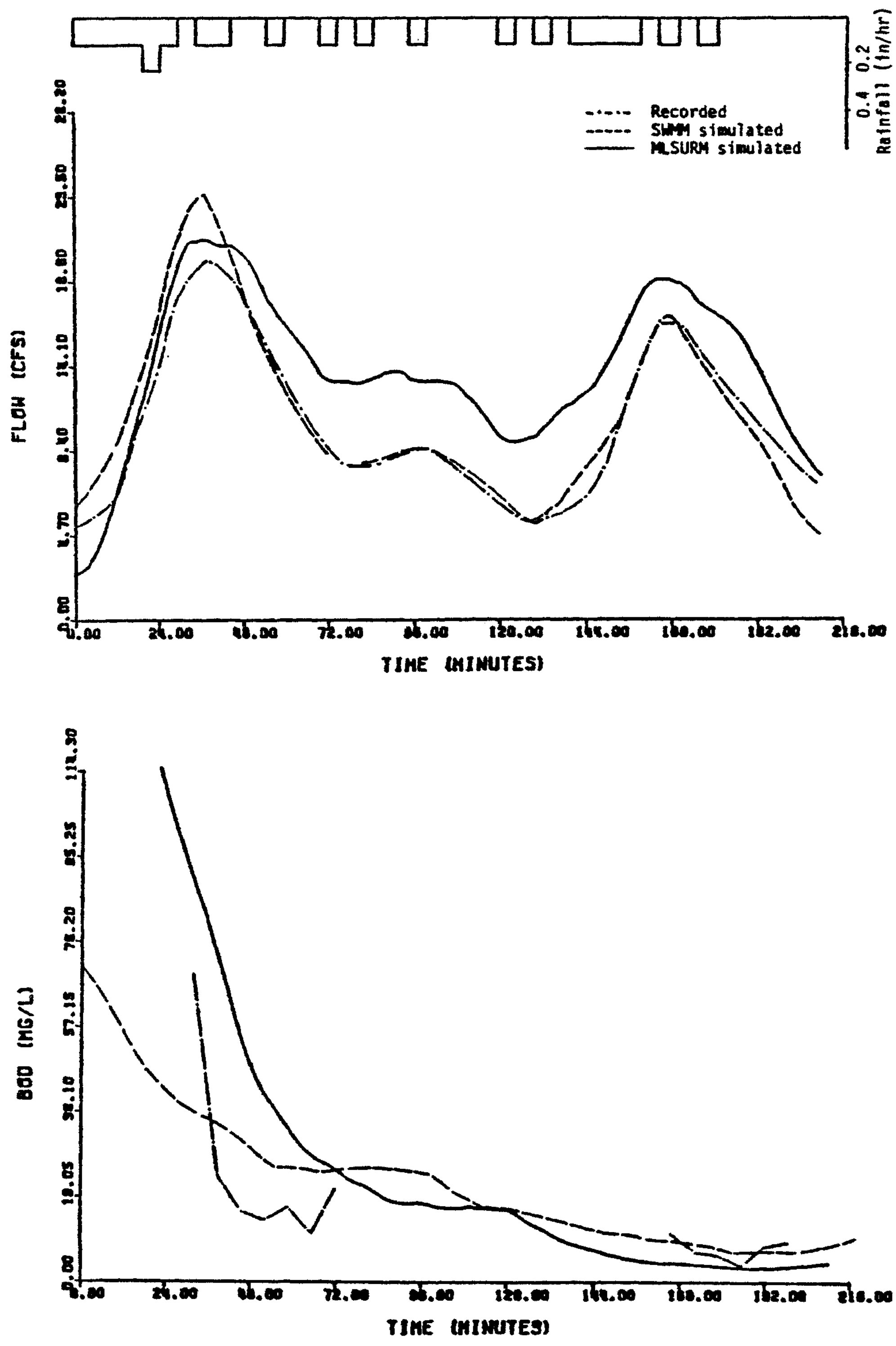


Figure 35 (continued) Results from Mortimer Avenue Basin
Toronto, Canada
Storm of April 25, 1976 (33)

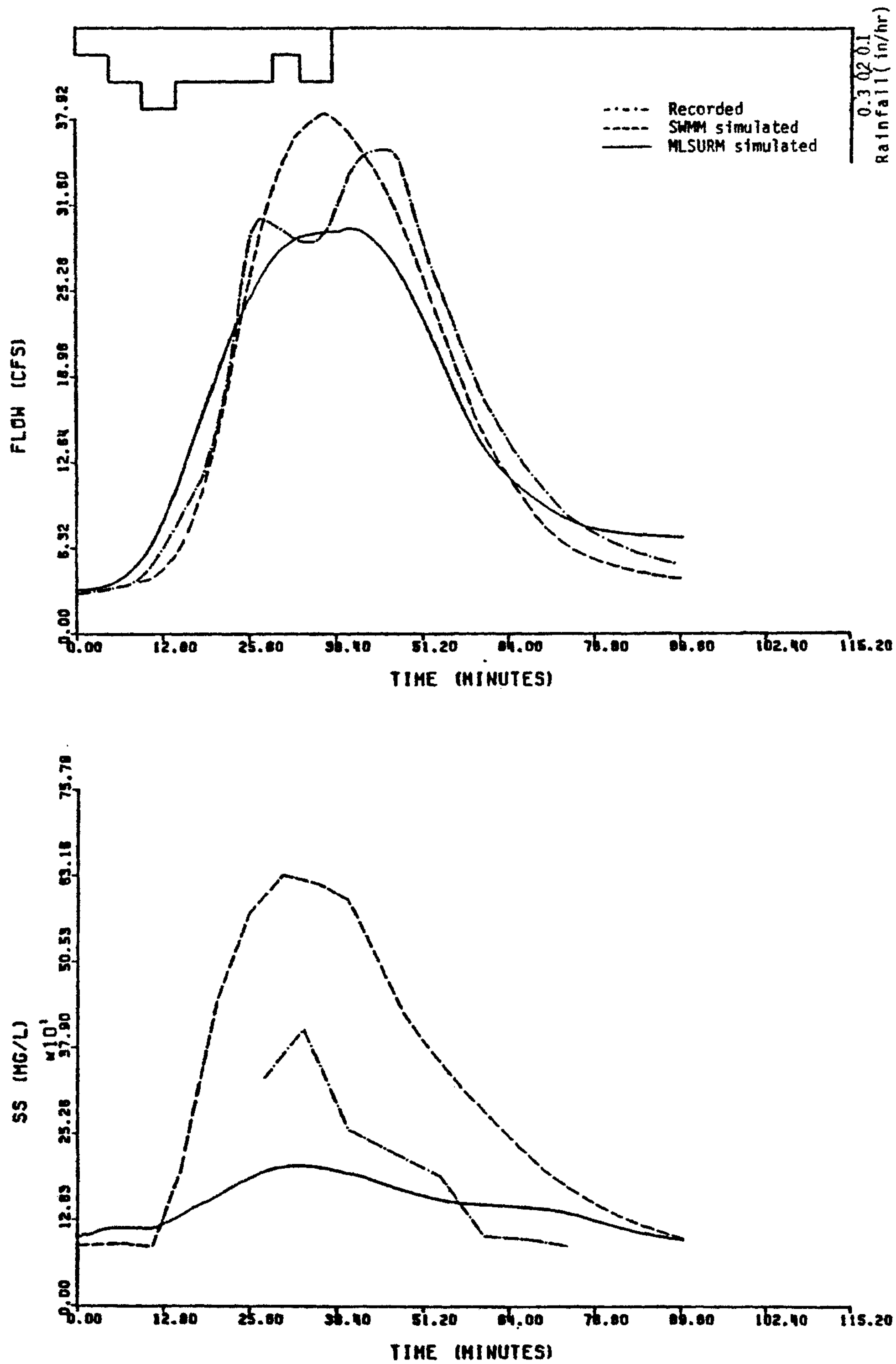


Figure 36 Results from Mortimer Avenue Basin, Toronto, Canada
Storm of May 11, 1976 (33)

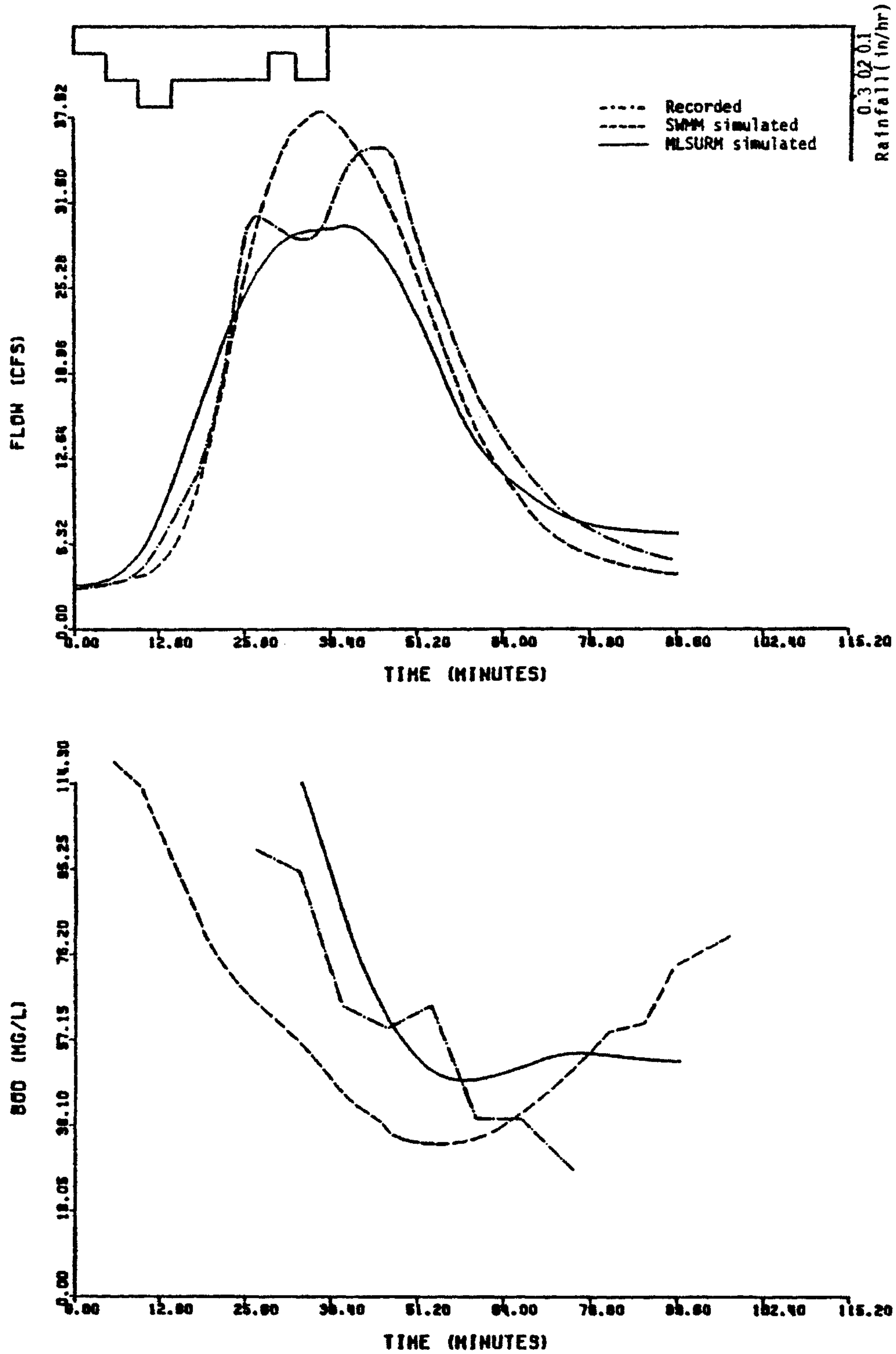


Figure 36 (continued) Results from Mortimer Avenue Basin,
Toronto, Canada
Storm of May 11, 1976 (33)

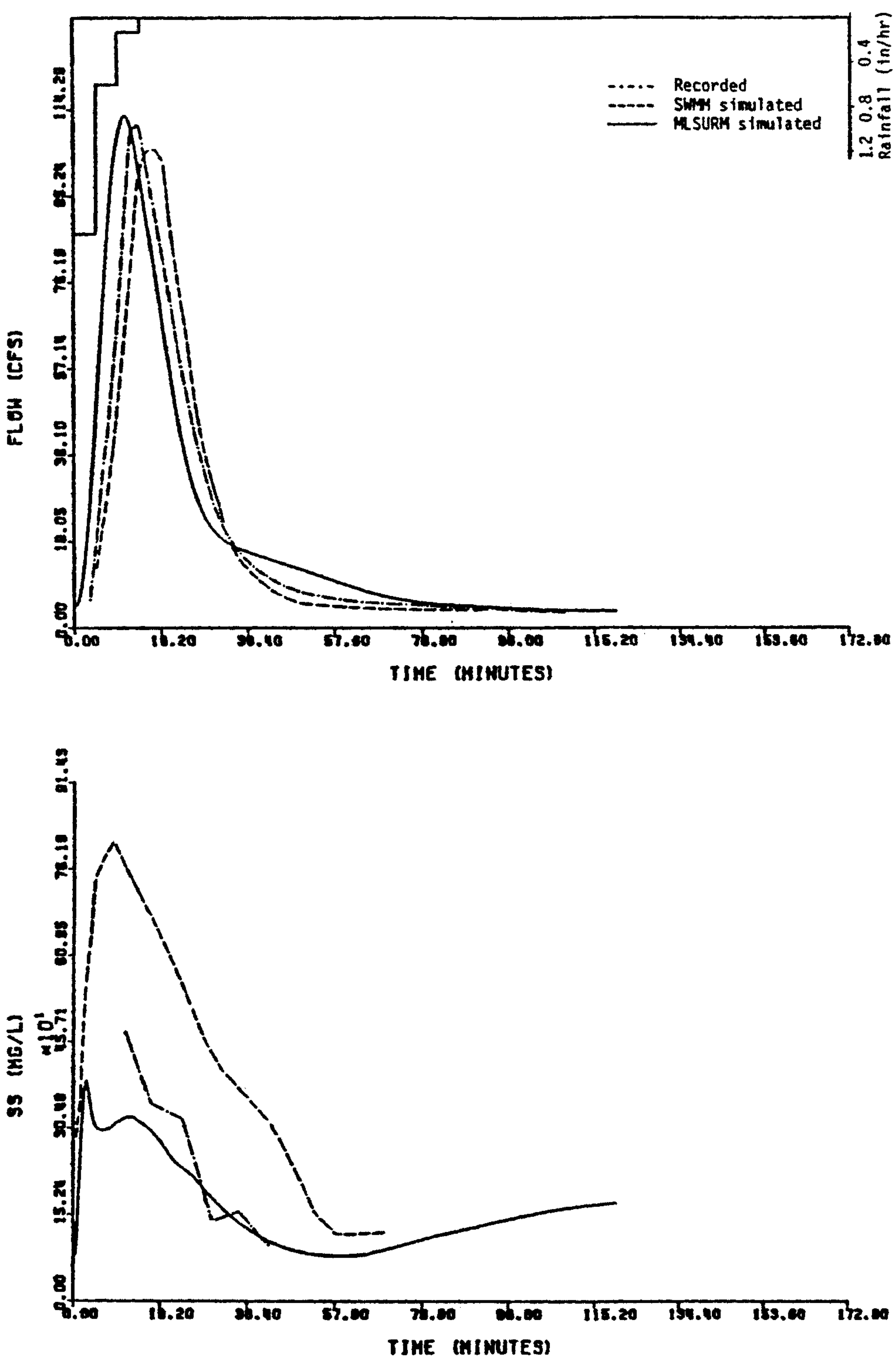


Figure 37 Results from Mortimer Avenue Basin, Toronto, Canada Storm of July 1, 1976 (33)

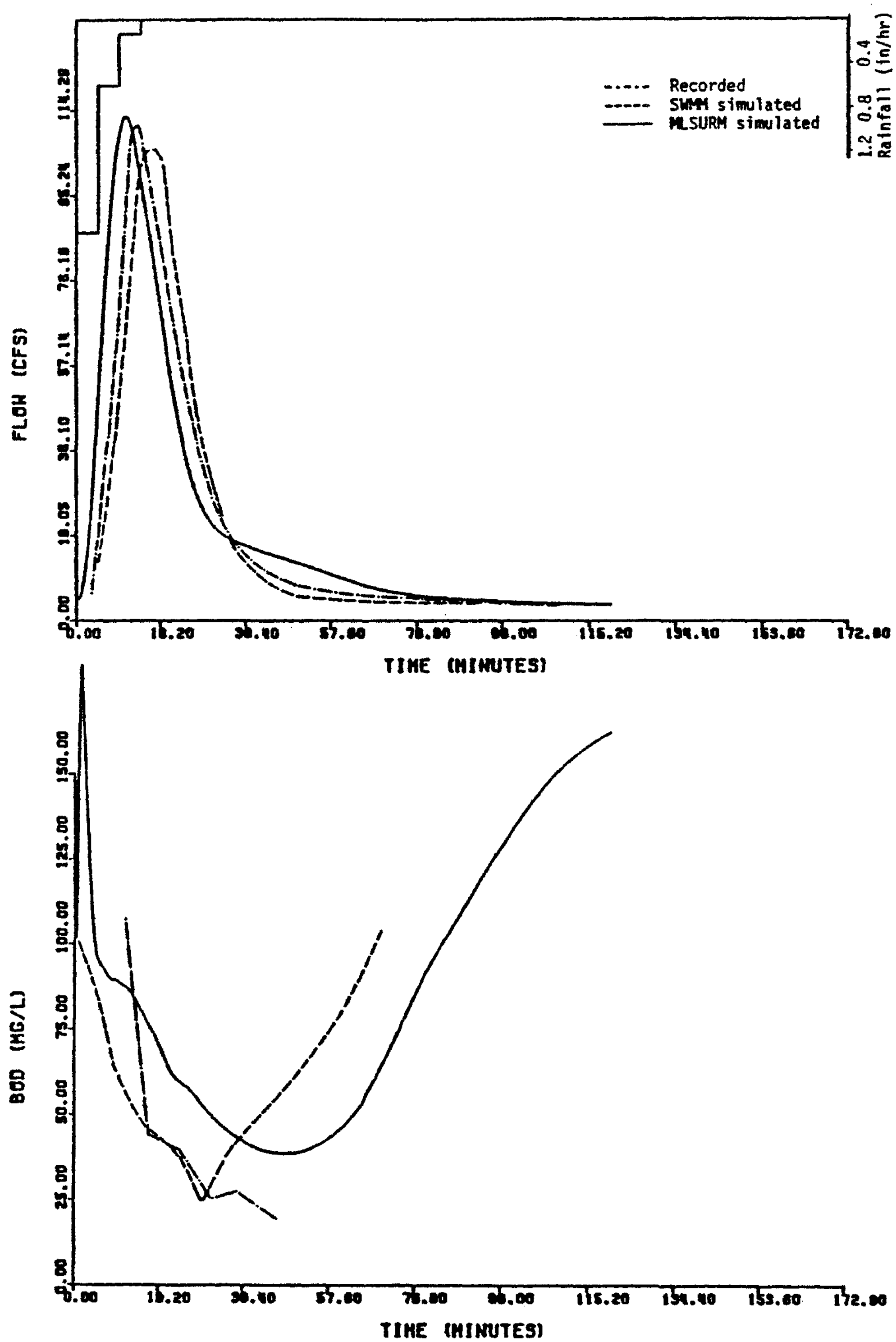


Figure 37 (continued) Results from Mortimer Avenue Basin,
Toronto, Canada
Storm of July 1, 1976 (33)

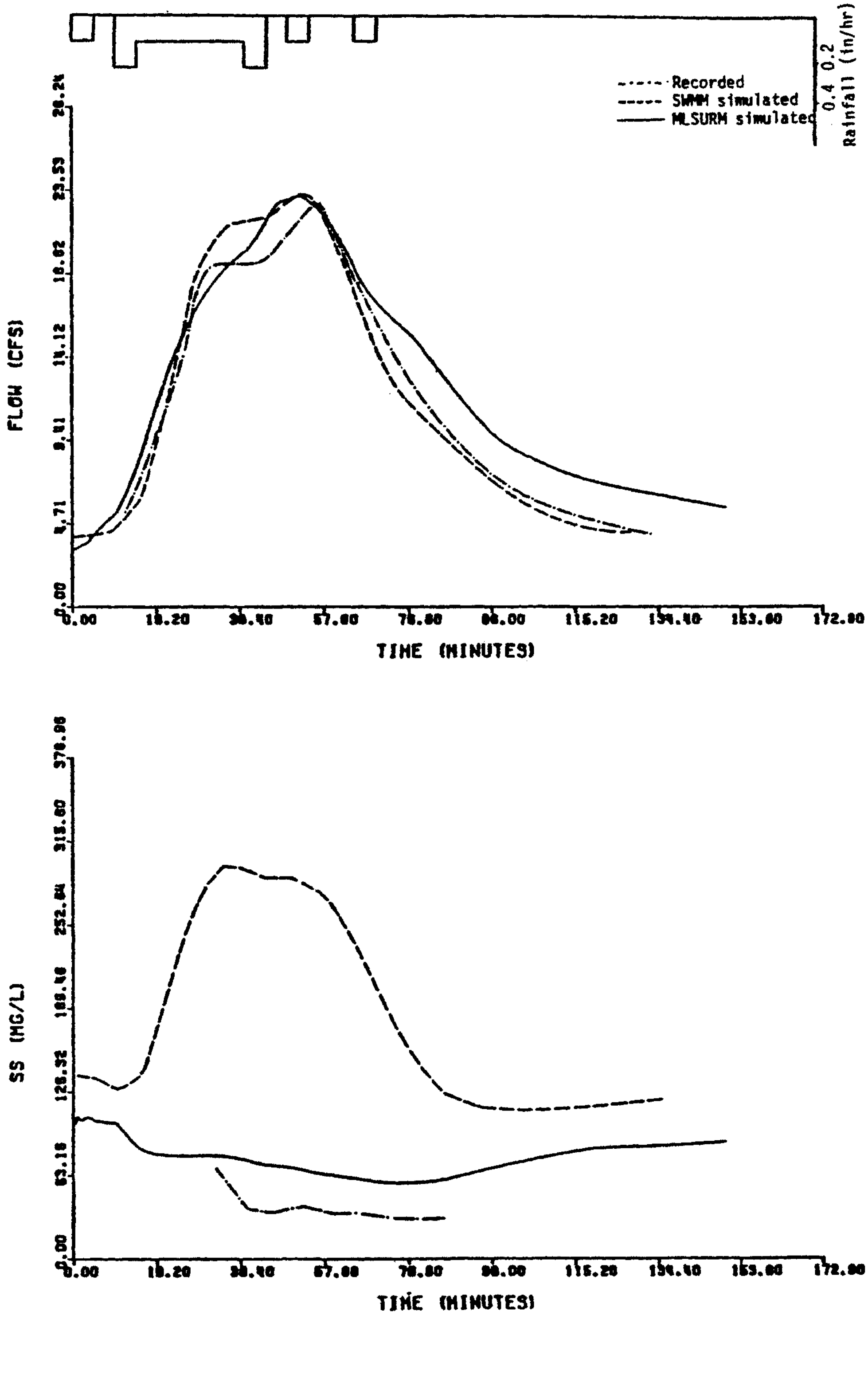
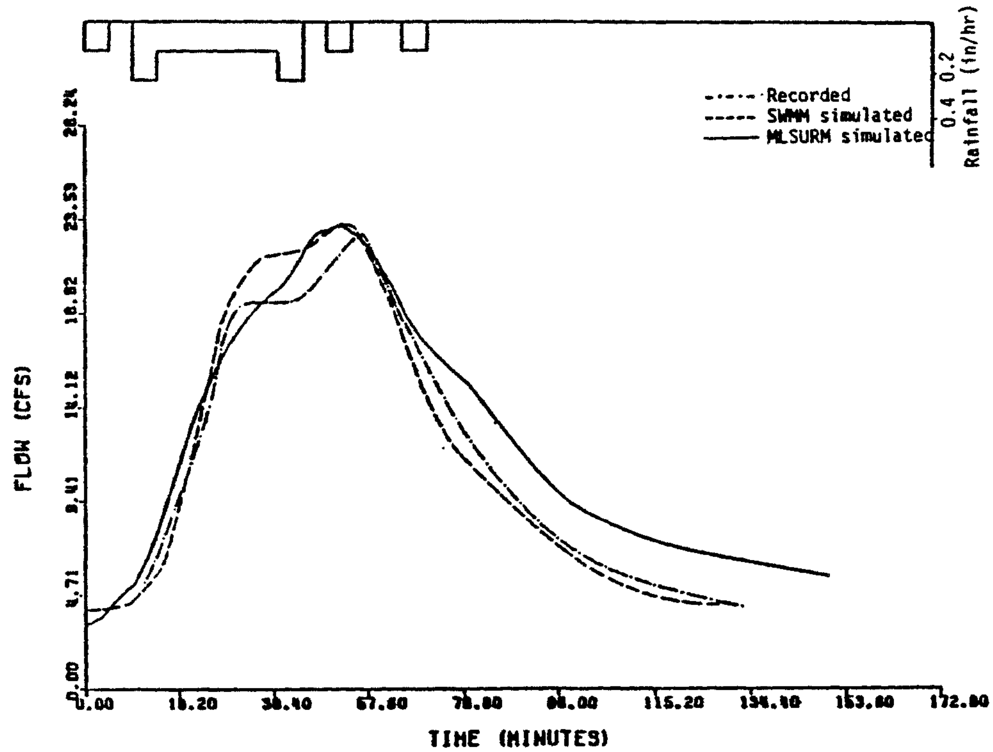


Figure 38 Results from Mortimer Avenue Basin, Toronto, Canada
Storm of July 2, 1976 (33)



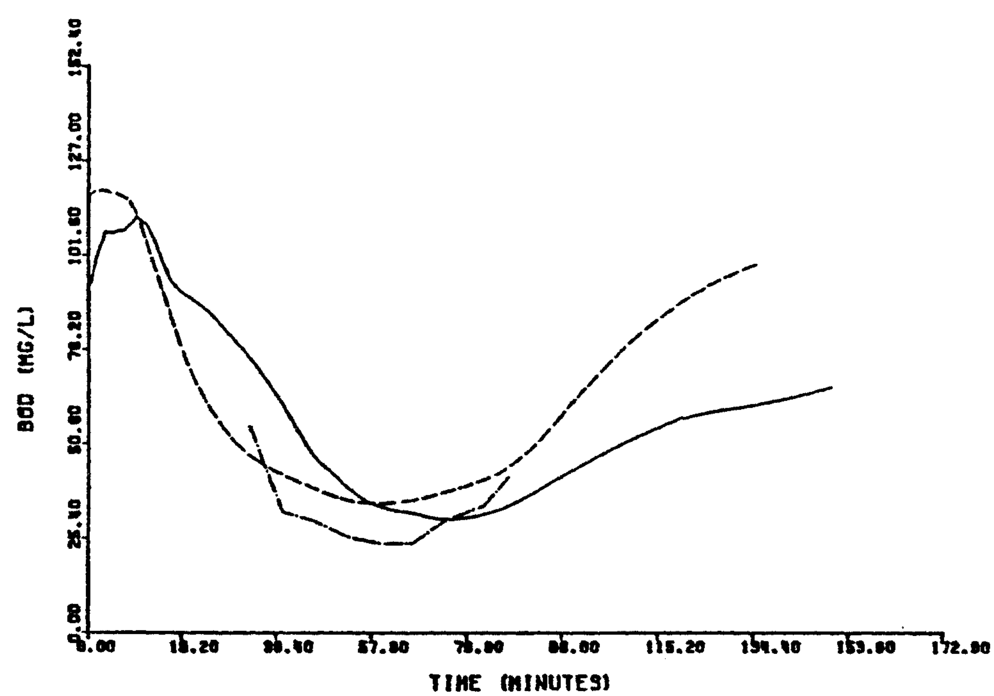


Figure 38 (continued) Results from Mortimer Avenue Basin, Toronto, Canada
Storm of July 2, 1976 (33)

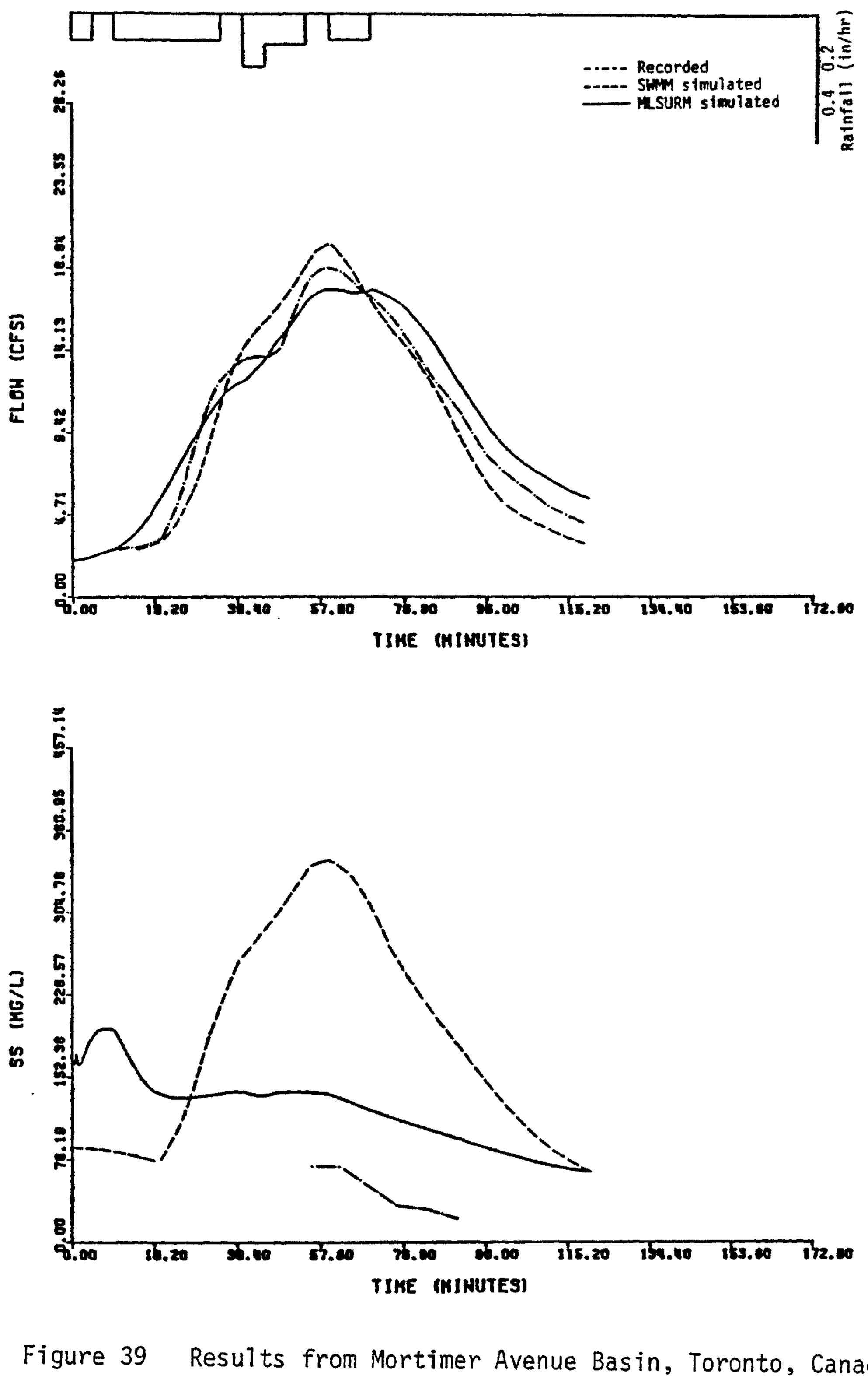
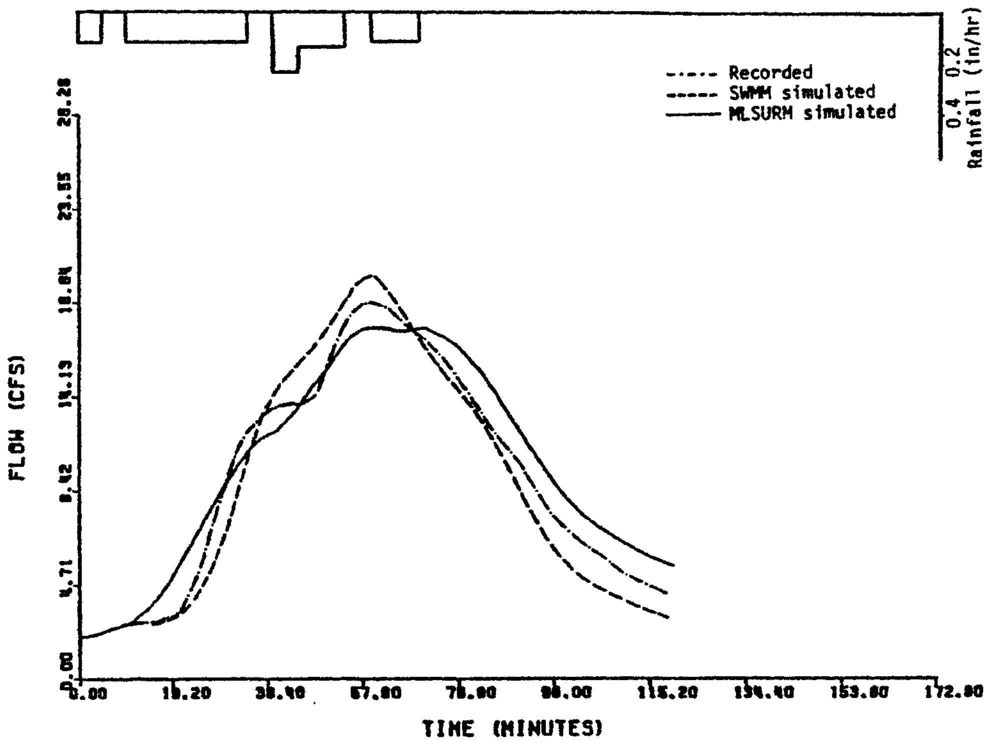


Figure 39 Results from Mortimer Avenue Basin, Toronto, Canada
Storm of July 11, 1976 (33)



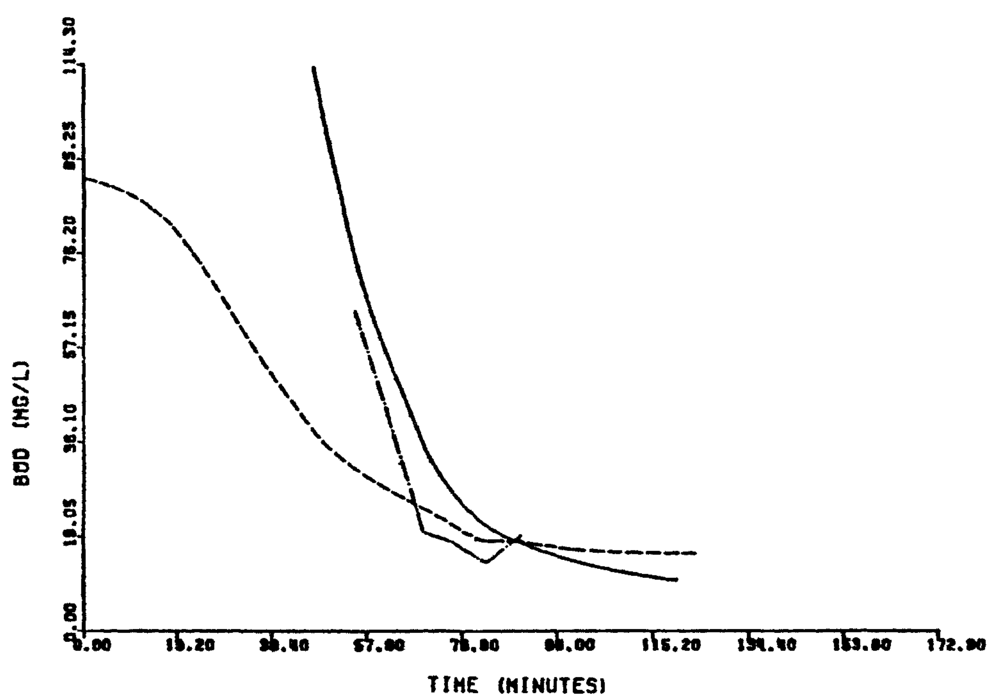


Figure 39 (continued) Results from Mortimer Avenue Basin, Toronto, Canada
Storm of July 11, 1976 (33)

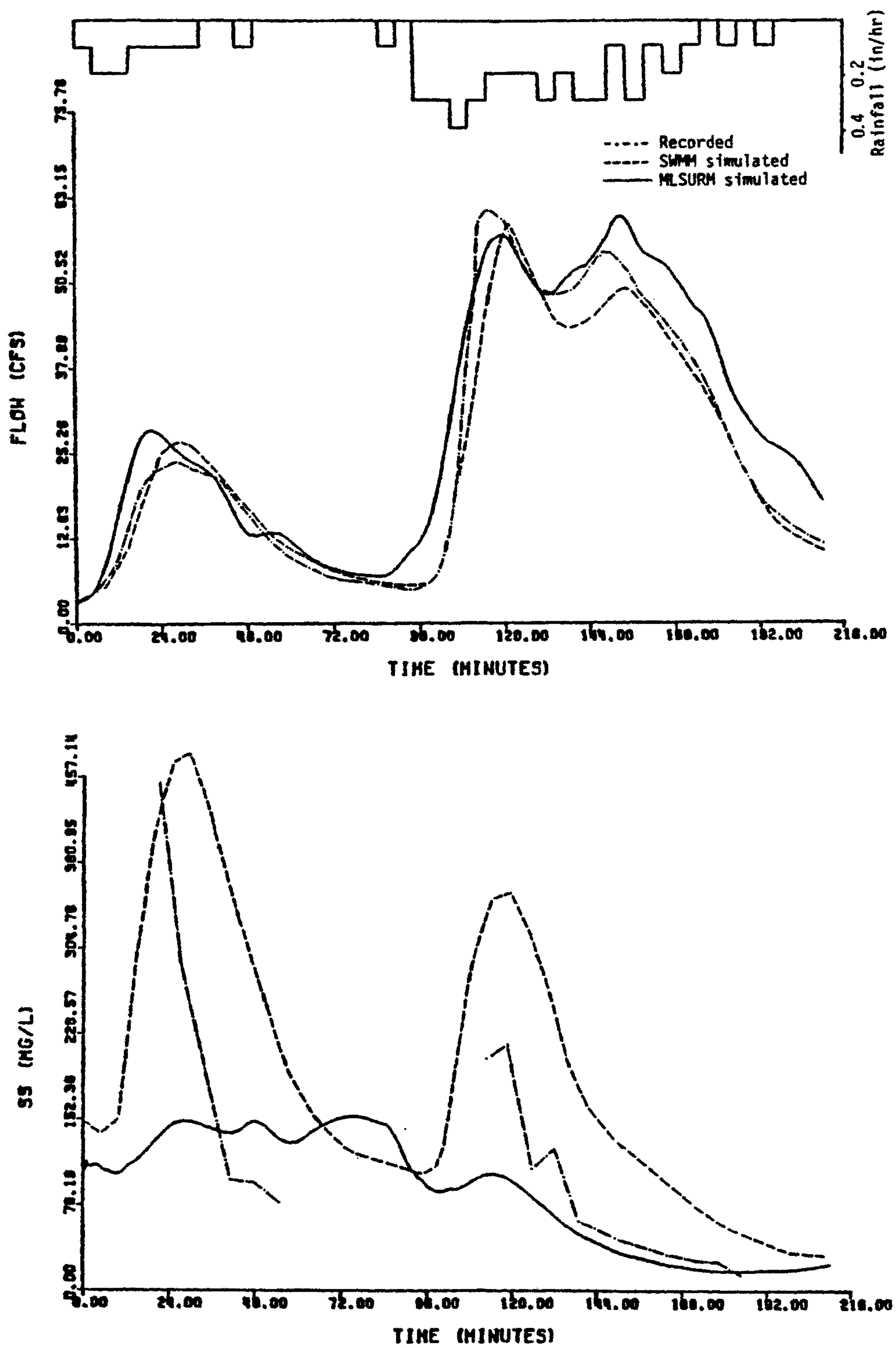


Figure 40 Results from Mortimer Avenue Basin, Toronto, Canada
Storm of July 20, 1976 (33)

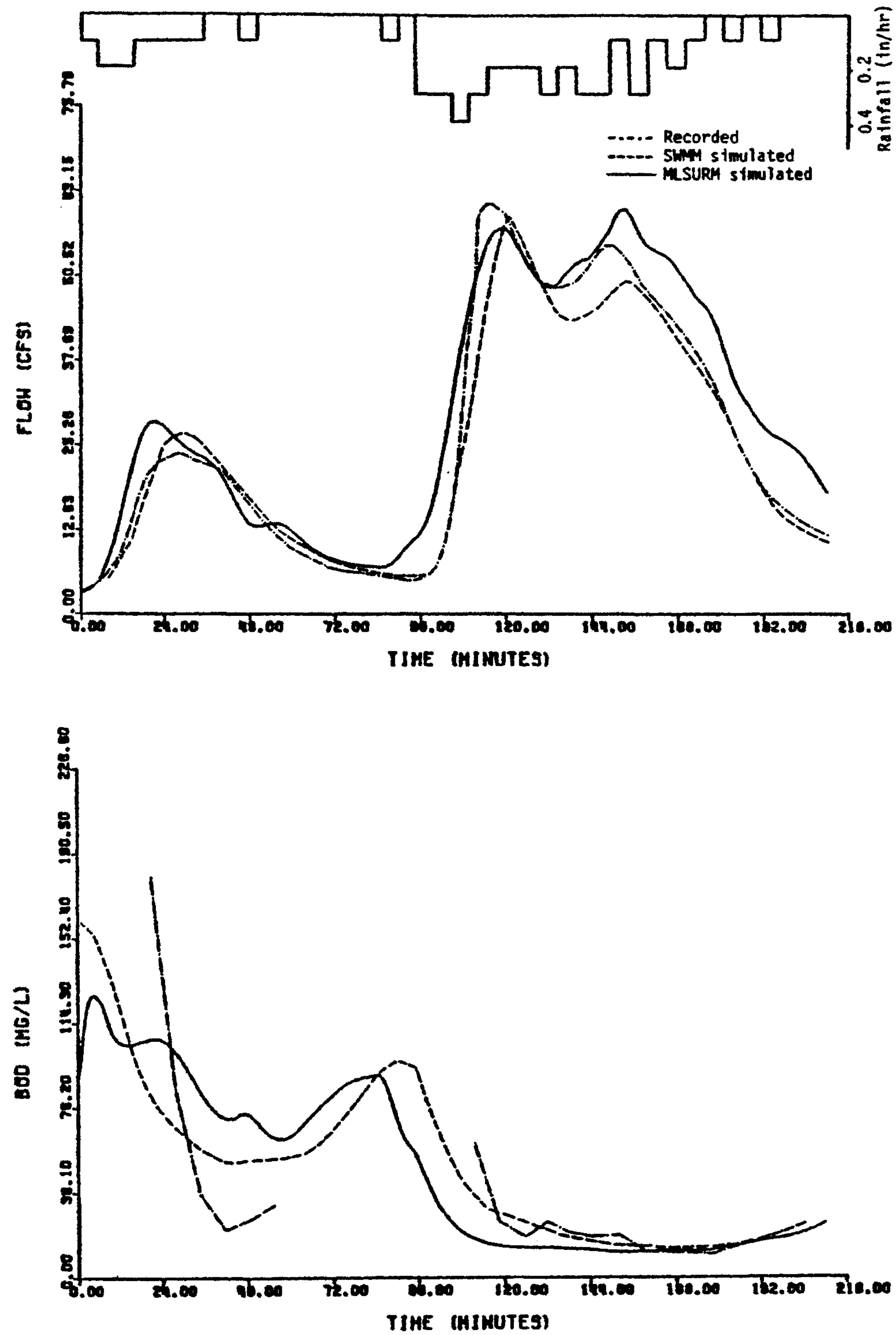


Figure 40 (continued) Results from Mortimer Avenue Basin,
Toronto, Canada
Storm of July 20, 1976 (33)

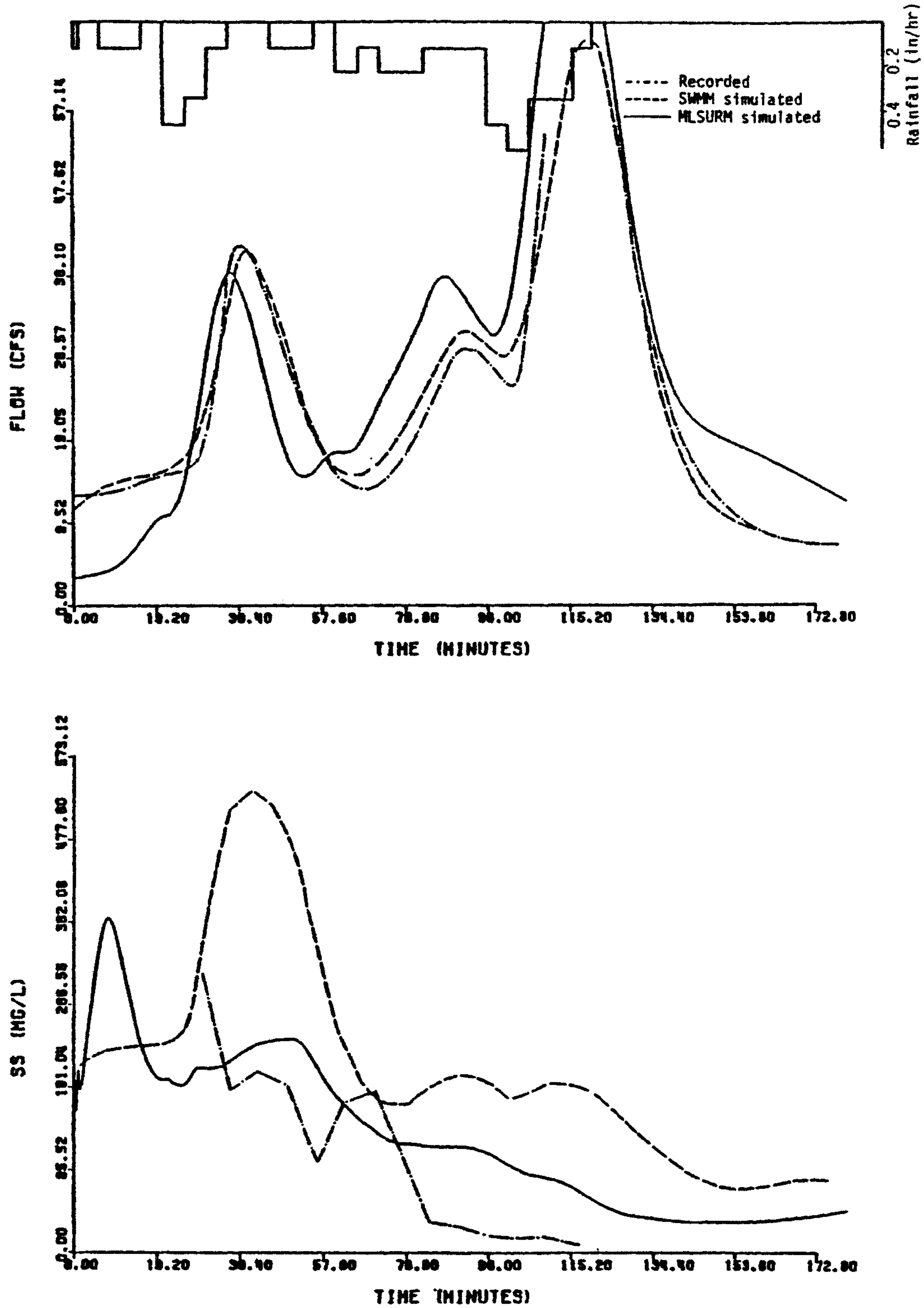


Figure 41 Results from Mortimer Avenue Basin, Toronto, Canada Storm of July 29, 1976 (33)

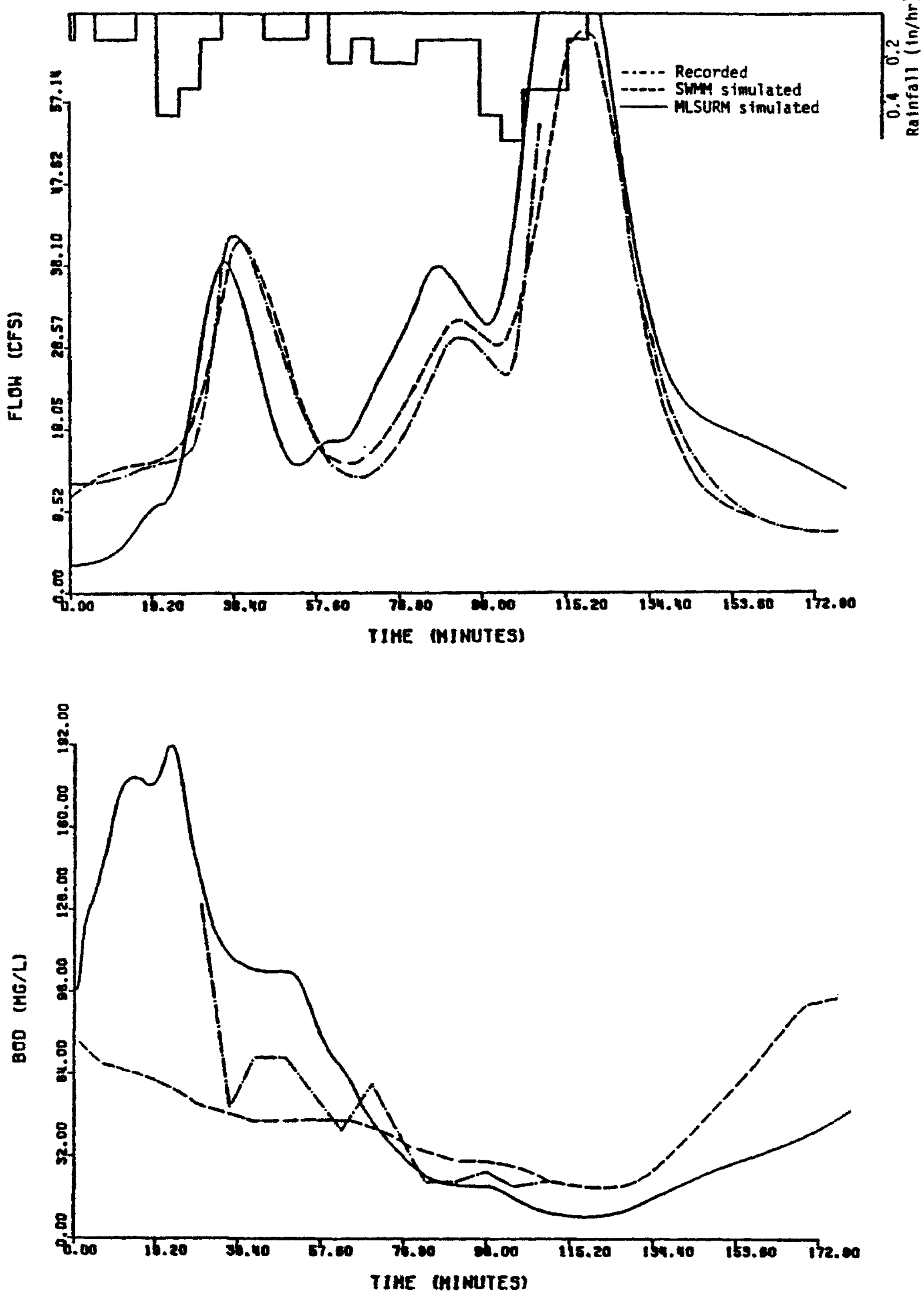


Figure 41 (continued) Results from Mortimer Avenue Basin,
Toronto, Canada
Storm of July 29, 1976 (33)

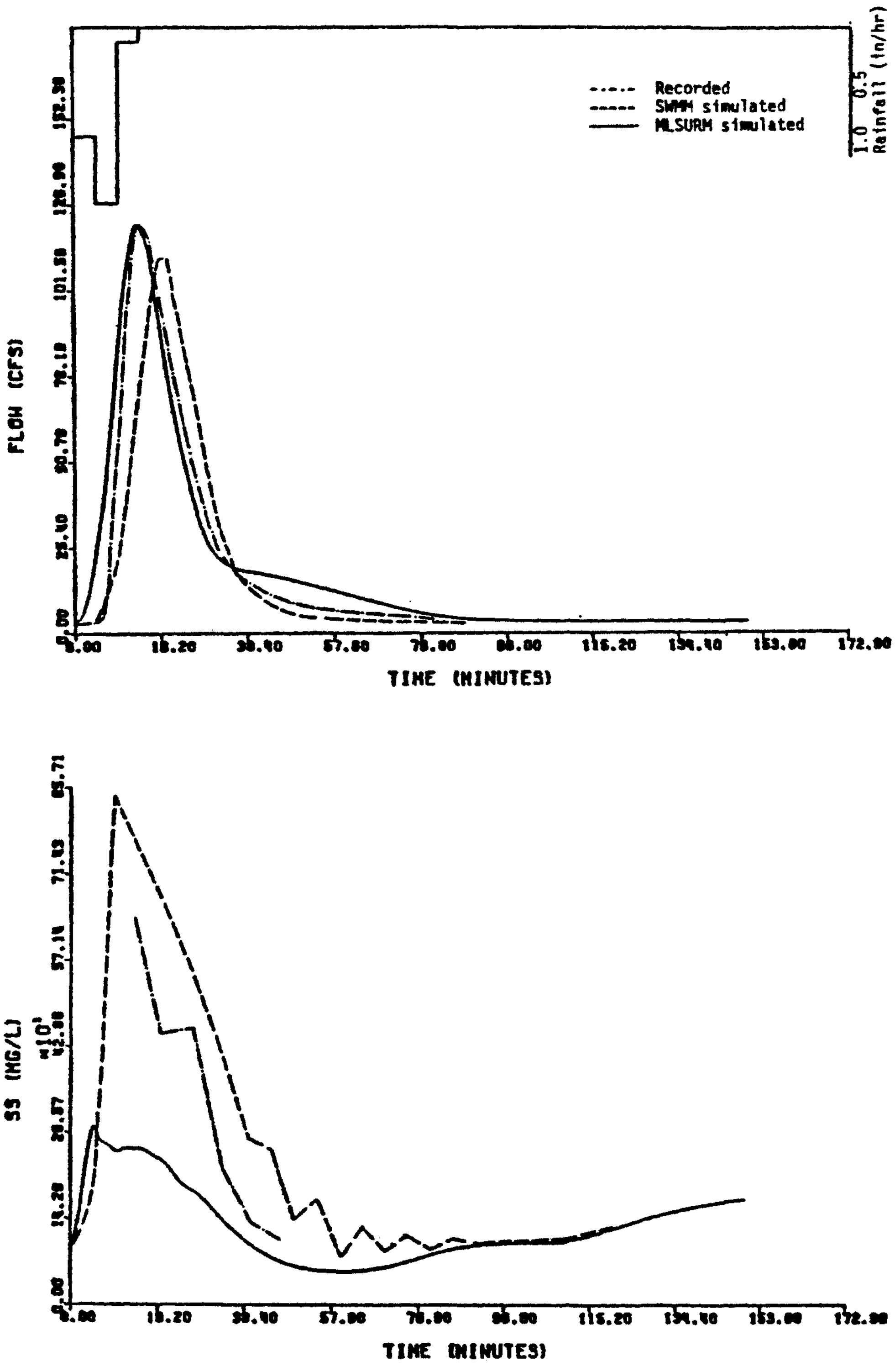


Figure 42 Results from Mortimer Avenue Basin, Toronto, Canada
Storm of August 13, 1976 (33)

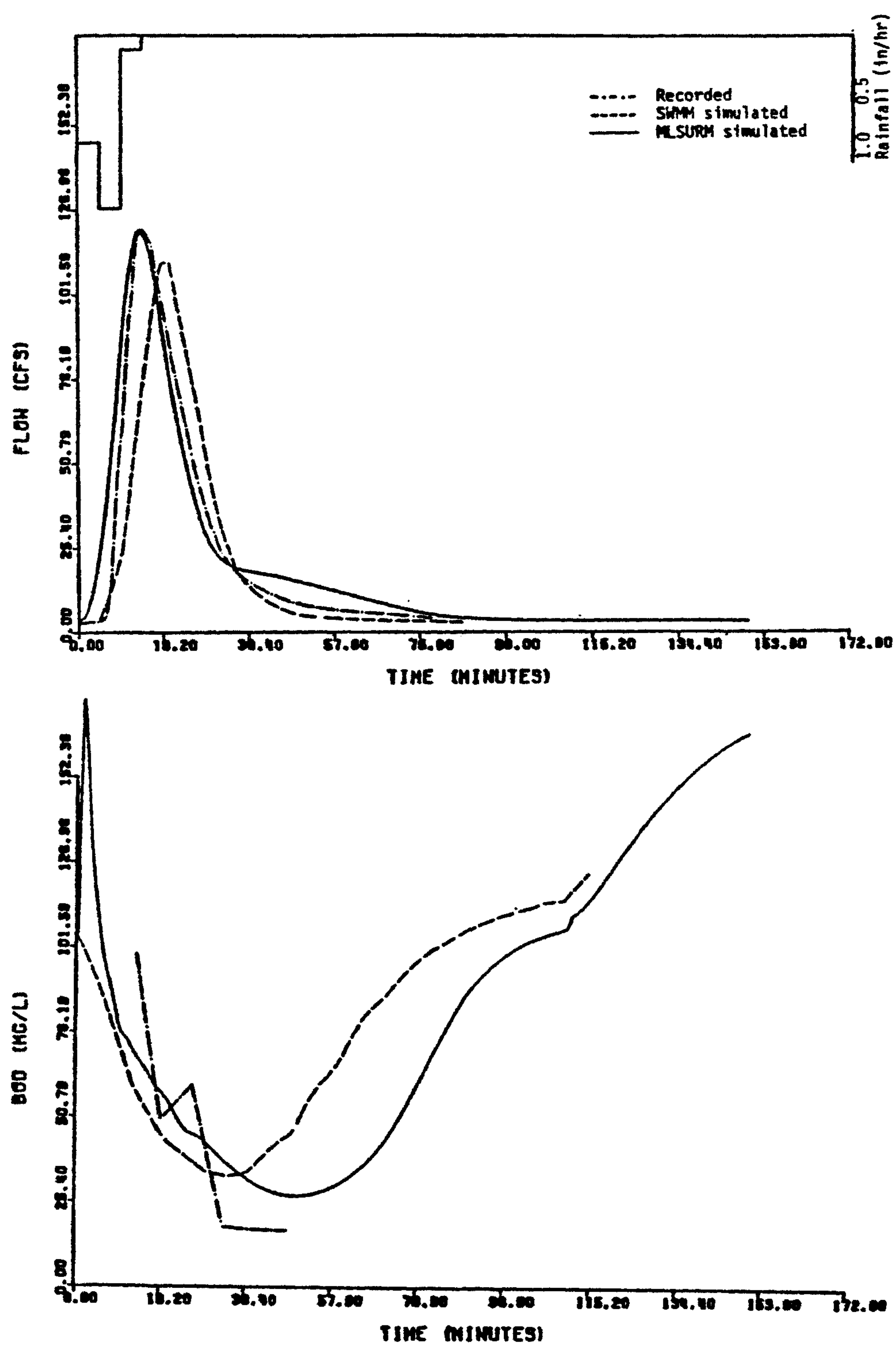


Figure 42 (continued) Results from Mortimer Avenue Basin,
Toronto, Canada
Storm of August 13, 1976 (33)

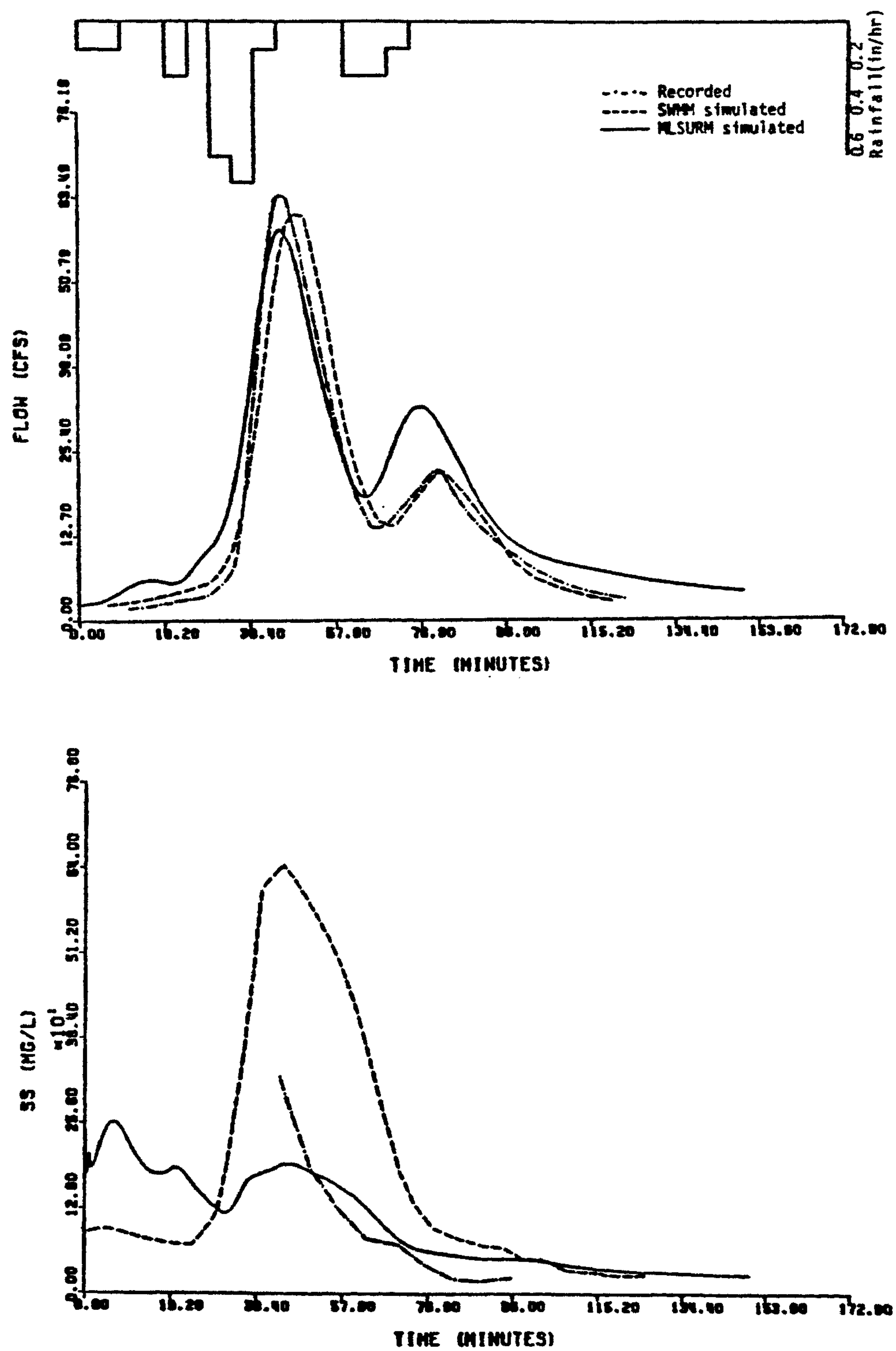


Figure 43 Results from Moritmer Avenue Basin, Toronto, Canada

Storm of September 1, 1976 (33)

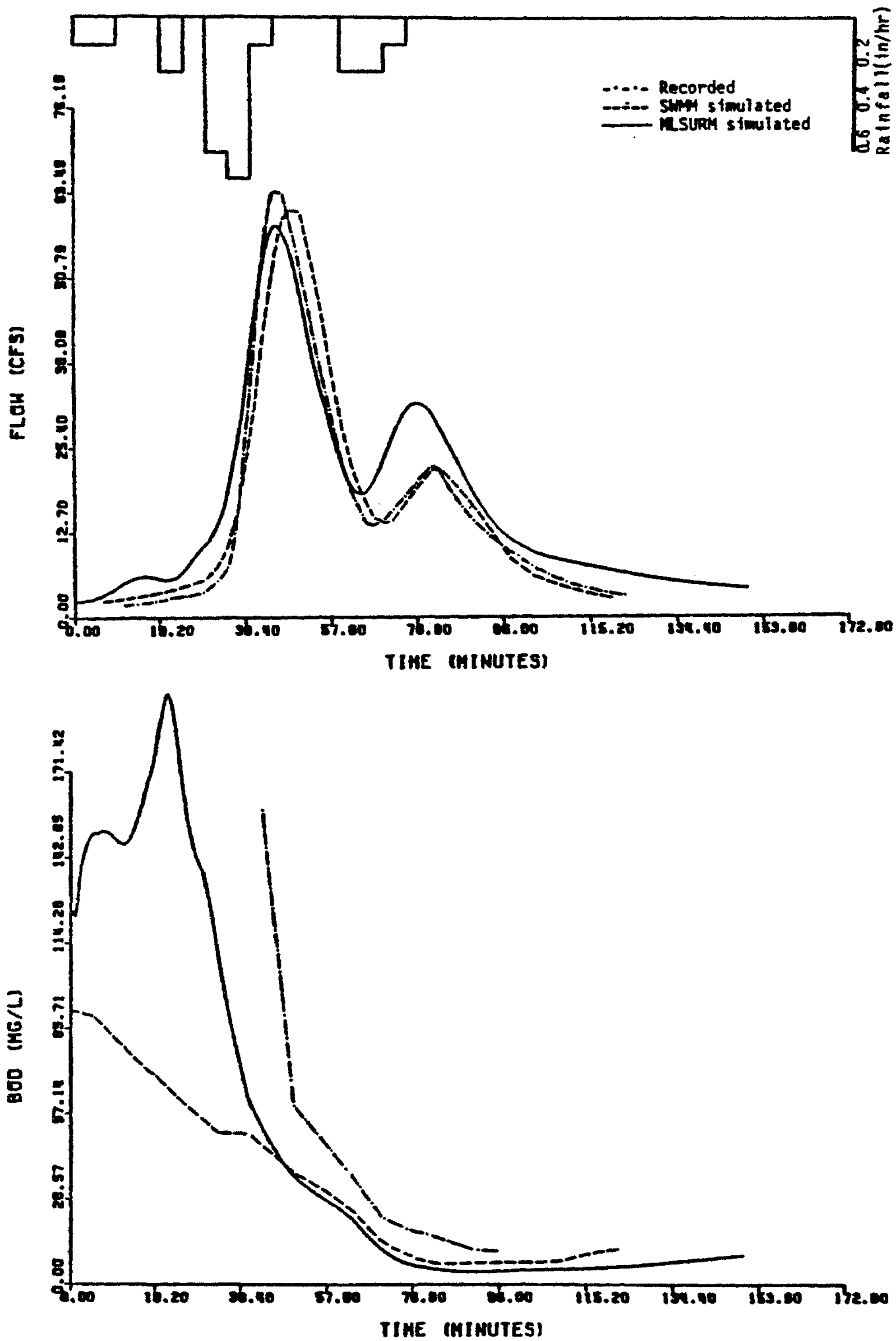


Figure 43 (continued) Results from Mortimer Avenue Basin,
Toronto, Canada
Storm of September 1, 1976 (33)

storm of July 29, 1976 as shown in Figure 41. However, it is noted that the MLSURM model predicted lower suspended solids concentration during early periods of the storms on July 1, 1976, July 20, 1976, August 13, 1976 as shown in Figures 37, 40, and 42. This is probably caused by the use of the availability factor $\bar{A}$ as given in equation (41) which is obtained based on data from the Cincinnati area rather than data pertinent to the Toronto region. For the simulation of the BOD pollution level, the predicted pollutographs for each storm are more consistent because the model does not include the availability factor in the simulation process of soluble pollutant such as BOD. It is felt that more satisfactory simulation of suspended solids can be accomplished with extensive investigations of the availability factor. However, this is beyond the financial resources of this study.

CHAPTER VII

SUMMARY

An urban runoff model entitled MLSURM is developed for the simulation of stormwater quantity and quality. The model is intended to be used as a tool in the planning and analysis of stormwater systems. The data required for the implementation of the model can be obtained from the following:

1) Synthetic hyetographs or recorded precipitation data for the area under consideration.
2) Topographic map of the drainage basin.
3) Existing or schematics of the planned stormwater system
4) Land use maps or aerial photographs
5) Census tract information pertinent to the drainage basin.

The following conclusions are reached based on the test application of the model:

1) The model simulated stormwater hydrographs well for small urban catchments with little calibration effort. The successful simulation of hydrographs for large watersheds is also achieved if the watersheds are subdivided into small catchments.

2) Model calibration is required for the pollutograph simulation due to lack of pertinent information about the amount of pollutant accumulated on the surface prior to a storm. Satisfactory results of BOD pollutograph simulation, however, are obtained by using calibrated parameter values.

3) Inclusion of the availability factor in the suspended solids simulation process results in inconsistencies of suspended solids pollutographs. Further studies are needed to evaluate the validity of the availability factor

The model may be applied to the investigation of the following problems.

1) Analysis of existing sewer systems:
Floods resulting from the deficiencies in the sewer system can be identified at various locations in the sewer network. Alternate relief strategies then can be tested to solve the problem.

2) Design of new sewer systems:
The model generates runoff values for a given area resulting from synthetic or measured hyetographs. Subsequently pipe sizes are determined for peak discharges.

3) Land use planning:
Cost-effective watershed planning in regard to the

problem of floods and pollutant loadings under various land use policies can be analyzed efficiently.

4) Effective land management strategies:
The model can be used to study the effectiveness of different land management strategies such as drainage modifications, street cleaning, sewer flushing, retention ponds, etc.

The model does have, however, limitations that must be pointed out:

1) Only single-event simulation is performed by the model. Long term simulation requires several consecutive runs of the program.
2) Snow accumulation and melt are not simulated.
3) Backwater effect is not simulated in the sewer flow routing. The model does not take into account the phenomena of flow reversal and routing through diverging systems.

It is recommended that further research be directed toward the following:

1) The model should be applied to more watersheds including urban, suburban, and rural areas where runoff quantity and quality data are available.

2) Verifications of model's quality simulation should be continued for as many quality constituents as possible.
3) Studies to determine the relationship between the surface pollutant rate constant K and drainage surface characteristics, and types of pollutants would be valuable.
4) Further investigation on the availability factor $\overline{A}$ used in suspended solids simulation process would improve the simulation results of suspended solids.
5) Expanding the model's capability in dealing with long term continuous simulation will provide the useful information in establishing the frequency of occurrence of floods and pollutant loadings.

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APPENDIX

Primary Program Listing

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                              (ENTRANCE)
                                  I
                                  I
**********************************************************************
*C                                                                   *
*C                                                                   *
*C                                                                   *
*C                                                                   *
*C                                                                   *
*C   **   **   **   **   **   **   **   **   **   **   **   **   **   **  *
*C                                                                   *
*C                                                                   *
*C                                                                   *
*C                            M L S U R M                            *
*C                                                                   *
*C                                                                   *
*C                                                                   *
*C      A MODIFIED LINEARIZED SUBHYDROGRAPHS URBAN RUNOFF MODEL       *
*C                                                                   *
*C                               FOR                                 *
*C                                                                   *
*C                  STORMWATER QUANTITY AND QUALITY                  *
*C                                                                   *
*C                                                                   *
*C                                                                   *
*C   **   **   **   **   **   **   **   **   **   **   **   **   **   **  *
*C                                                                   *
*C                                                                   *
*C                                                                   *
*C                                                                   *
*       REAL*8 PNAME                                                 *
*       REAL S                                                       *
*       COMMON/BUF    / TITLE(20)                                    *
*       COMMON/LOGIC  / QNFLAG,QLFLAG                                *
*       COMMON/CONTRL/ DWFDCO(7),DWFHCO(24),                         *
*      &               DELTA,AINTER,AROC,KONTRL,KDAY,KHOUR,KMIN,     *
*      &               NN,NP,MAXTIM,NRAIN,MXRNIN,KALMS,NCHEX,NSUB    *
*       COMMON/LCONTR/ SSDCO(7),BODDCO(7),SSHCO(24),BODHCO(24),COLHCO(24),*
*      &               DRYDAY,CLFREQ,DWFDAY,NOPASS,NPOLL             *
*       COMMON/LCONTI/ LOADDD,IDATA                                  *
*       COMMON/COMDWF/ CPI,CCCI,PCPULA,ADWF,TOTA,TINA,TCA,TRHA,TRAA, *
*      &               TRLA,TRCSA,TPDA,SUMQPF,C2DWF,CF,CF2,SMTDWF,   *
*      &               TOTPOP,SUMSS,SUMBOD,KASE,NPF                  *
*       COMMON/NPOINT/ NR01,NR02,NR03,NR04,NR05,NR06,                *
*      &               NB10,NB01,NB02,NB03,NB04,NB05,NB06,NB07,NB08, *
*      &               NB09,NB10,NB11,NG01,NG02,NG03,NG04,NG05,NG06, *
*      &               NG07,NG08,                                    *
*      &               ND01,ND02,ND03,ND04,ND05,ND06,ND07,NDPF,      *
*      &               NS10,NS01,NS02,NS03,NS04,NS05,NS06,NS07,NS08, *
*      &               NS09,NS10,NS11,                               *
*      &               NGOV,NTGV,NCVG,NTGT,NSBH,                     *
*      &               NXTS,NBSF,NBGT,NTSW,NOFU,NXLD,NQSW            *
*       COMMON/LPOINT/ LP10,LK00,LNSB,LNCB,LVCB,LCB1,LCB2,           *
*      &               LUSE,LCRB,LSAR,                               *
*      &               LPDW,LSSS,LBDS,LCLS,                          *
*      &               LTDD,LVOL,LHRD,LBDD,LBED,LBSS,                *
*      &               LPOV,LFIN,LFED,LCPO,LHSP,LPRC,LOOP01          *
*       COMMON/CONST1/ SPG,BVAL                                      *
*       COMMON/CONST2/ DDLB(5),SSPOT(5),BODPOT(5),COLPOT(5),CODPOT(5),*
*      &               PNPOT(5),PO4POT(5)                            *
*       COMMON/CONST3/ PNAME(6),NALLOW                               *
```

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*       COMMON/INTPO / QIN(21),VAR(21),FUN(21)                                 *
*       COMMON/MXSIZE/ MSOS,LAST                                               *
*C                                                                             *
*C                                                                             *
*       COMMON S(20000)                                                        *
*C                                                                             *
*C                                                                             *
*C      ** N O T E **                                                          *
*C                                                                             *
*C      WHENEVER THE VALUE OF 'MSOS' IS CHANGED, THE                           *
*C      ASSOCIATED VALUE OF DIMENSION OF 'S' ARRAY IN THE                      *
*C      BLANK COMMON BLOCK HAS TO BE CHANGED TOO.                              *
*C                                                                             *
*C      MSOS: THE MAXIMUM STORAGES RESERVED FOR 'S' ARRAY                      *
*C                                                                             *
*       MSOS=20000                                                             *
*C                                                                             *
*C      LIST INPUT DATA CARD IMAGES                                            *
*C                                                                             *
*       CALL CARD                                                              *
*C                                                                             *
*C      EXECUTION IS DRIVEN IN (XQTION) SUBROUTINE                             *
*C                                                                             *
*       CALL XQTION                                                            *
********************************************************************************
                                       I
                                       I
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*       STOP                                                                   *
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********************************************************************************
*       END                                                                    *
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                                                (ENTRANCE)
                                                    I
                                                    I
*****************************************************************************
*       SUBROUTINE CARD                                                     *
*C                                                                          *
*C                                                                          *
*C   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .*
*C   .                                                                     .*
*C   .   P R O G R A M                                                     .*
*C   .        TO PRODUCE A CARD IMAGE LISTING OF THE INPUT FILE (UNIT 5)   .*
*C   .                                                                     .*
*C   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .*
*C                                                                          *
*C                                                                          *
*       DIMENSION DATA(20)                                                  *
*       INPUT=5                                                             *
*C                                                                          *
*       REWIND INPUT                                                        *
*C                                                                          *
*    20 CONTINUE                                                            *
*       WRITE (6,2000)                                                      *
*       KARD   = 0                                                          *
*       KARDNO = 0                                                          *
*****************************************************************************
                                                    I
                                                    O<.........................................O
                                                    I                                          B
*****************************************************************************                  B
*    30 READ (5,1000,END=60) DATA                                           *                  B
*    40 KARD=KARD + 1                                                       *                  B
*       KARDNO=KARDNO + 1                                                   *                  B
*****************************************************************************                  B
                                                    I                                          B
                                                    I                                          B
                                                    I                                          B
*****************************************************************************                  B
*       IF(KARDNO.LE.43) GO TO 30                                           *..................B.......O
*****************************************************************************                  B       F
                                                    I                                          B       F
                                                    I                                          B       F
                                                    I                                          B       F
*****************************************************************************                  B       F
*       WRITE (6,2010)                                                      *                  B       F
*       WRITE (6,2000)                                                      *                  B       F
*       KARDNO=1                                                            *                  B       F
*****************************************************************************                  B       F
                                                    I                                          B       F
                                                    I                                          B       F
```

```
                                                     I                                                                         B        F
                                                     0<.....................................................B.......0
                                                     I                                                                          B
**********************************************************************              B
*    50 WRITE (6,2020) KARD,DATA                                                           *              B
**********************************************************************              B
                                                     I                                                                          B
                                                     I                                                                          B
                                                     I                                                                          B
**********************************************************************              B
*         GO TO 30                                                                                 *......0
**********************************************************************


**********************************************************************
*    60 WRITE (6,2010)                                                                             *
*         WRITE (6,2030)                                                                           *
*         REWIND INPUT                                                                             *
*C                                                                                                    *
**********************************************************************
                                                     I
                                                     I
                                                     I
**********************************************************************
*         RETURN                                                                                    *
**********************************************************************


**********************************************************************
*C                                                                                                    *
* 1000 FORMAT (20A4)                                                                               *
* 2000 FORMAT(1H1/10X,111HF O L L O W I N G    I S    A   C A R D    I M*
*         & A G E    L I S T I N G    O F    T H I    I N P U T    D A T A //*
*         &58X,26HC O L U M N    N U M B E R,/20X,4HCARD,16X,71H1          2  *
*         &          3          4          5          6          7          8 /  *
*         &19X,6HNUMBER, 6X,80H12345678901234567890123456789012345678901234567890123456*
*         &78901234567890123456789012345678 9) /,19X,6(1H-),5X,80(1H-))         *
* 2010 FORMAT (19X,6(1H-),6X,80(1H-),                                                    *
*         &          /20X,4HCARD,16X,71H1          2          3          4          *
*         &5          6          7          8 /19X,6HNUMBER, 6X,30H1234567890123*
*         &4567890123456789012345678901234567890123456789012345678901234567890123456789*
*         &0 /58X,26HC O L U M N    N U M B E R )                                    *
* 2020 FORMAT (8X,I15,8X,20A4)                                                           *
* 2030 FORMAT(1H0,10X,34(1H*),44H E N D    O F    I N P U T    L I S T I *
*         &N G ,34(1H*))                                                                          *
*C                                                                                                    *
**********************************************************************
                                                     I
```

END

(ENTRANCE)

```
      SUBROUTINE XQTION
C
C
C
C    P R O G R A M
C       1. TO READ IN THE CASE STUDY TITLE AND THE
C             MASTER CONTROL PARAMETERS
C       2. TO DRIVE THE EXECUTION OF SIMULATION
C
C
C
C
      REAL*8 PNAME
      REAL S
      LOGICAL ONFLAG,OLFLAG
      COMMON/BUF    / TITLE(20)
      COMMON/LOGIC  / ONFLAG,OLFLAG
      COMMON/CONTRL/ DWFDCO(7),DWFHCO(24),
     &               DELTA,AINTER,AROC,KONTRL,KDAY,KHOUR,KMIN,
     &               NN,NP,MAXTIM,NRAIN,MXRNIN,KALMS,NCHEX,NSUB
      COMMON/LCONTR/ SSDCO(7),BODDCO(7),SSHCO(24),BODHCO(24),COLHCO(24),
     &               DRYDAY,CLFREQ,DWFDAY,NOPASS,NPOLL
      COMMON/LCONT1/ LOADOD,ICATA
      COMMON/COMDWF/ CPI,CCCI,POPULA,ADWF,TOIA,TINA,TCA,TRHA,TRAA,
     &               TRLA,TRGGA,TPOA,SUMOPF,C2DWF,CF,CF2,SMTDWF,
     &               TOTPOP,SUMSS,SUMBOD,KASE,NPF
      COMMON/NPOINT/ NR01,NR02,NR03,NR04,NR05,NR06,
     &               NB10,NB01,NB02,NB03,NB04,NB05,NB06,NB07,NB08,
     &               NB09,NB10,NB11,NG01,NG02,NG03,NG04,NG05,NG06,
     &               NG07,NG08,
     &               ND01,ND02,ND03,ND04,ND05,ND06,ND07,NDPF,
     &               NS10,NS01,NS02,NS03,NS04,NS05,NS06,NS07,NS08,
     &               NS09,NS10,NS11,
     &               NQOV,NTOV,NCVO,NTOT,NSBH,
     &               NXTS,NDSF,NDST,NTSW,NQFU,NXLD,NOSW
      COMMON/LPOINT/ LP10,LK07,LNSB,LNCB,LVCB,LCB1,LCB2,
     &               LUSE,LCRB,LSAR,
     &               LPOW,LSSS,LBDS,LCLS,
     &               LTDD,LVOL,LHRD,LBDO,LBED,LBSS,
     &               LPOV,LFIN,LFED,LCPO,LBSP,LPRC,LOOP01
      COMMON/CONST1/ SPG,BVAL
      COMMON/CONST2/ DDLR(5),SSPOT(5),BODPOT(5),COLPOT(5),CODPOT(5),
     &               PNPOT(5),PO4POT(5)
      COMMON/CONST3/ PNAME(6),NALLOW
      COMMON/INTPO / QIN(21),VAH(21),FJN(21)
      COMMON/MXSIZE/ MSOS,LAST
      COMMON S(1)
      DATA BLANK/4H    /
      NJOB=0
C
C     READ IN THE CASE STUDY TITLE WHICH IS AN ALPHA-NUMERIC STRING
C     OF  80 CHARACTERS LONG OF USER'S CHOICE
C
```

OK..O

```
  100 READ(5,1000,END=500)TITLE
 1000 FORMAT(20A4)
C
C      CHECK IF THE END OF THE JOBS
C

       DO 200 I=1,20

       IF(TITLE(I) .NE. BLANK)GO TO 300

  200 CONTINUE

       GO TO 500

  300 WRITE(6,2000)TITLE
 2000 FORMAT(1H1,28(/),25X,84(1H*),/,
      &                   25X,84(1H*),/,
      &                   25X,2H**,30X,2H**,/
      &                   25X,2H**,20A4,2H**,/,
      &                   25X,2H**,30X,2H**,/
      &                   25X,84(1H*),/,
      &                   25X,84(1H*))
C
C      SET THE CONTROL FLAGS
C
       QNFLAG=.FALSE.
       QLFLAG=.FALSE.
C
C      KONTRL:SIMULATION CONTROL PARAMETERS
C        EQ.1 IF BOTH QUANTITY AND QUALITY SIMULATION OF COMBINED SYSTEM
C        EQ.2 IF BOTH QUANTITY AND QUALITY SIMULATION OF SEPERATE SYSTEM
C        EQ.3 IF ONLY QUANTITY SIMULATION OF COMBINED SYSTEM
C        EQ.4 IF ONLY QUANTITY SIMULATION OF SEPERATE SYSTEM
C
C      KDAY:THE DAY OF THE WEEK THE SIMULATION(STORM) BEGINS
C        EQ.1 FOR SUNDAY
C        EQ.2 FOR MONDAY
C          .        ..
C          .        ..
```

```
*C
*C      KHOUR:THE HOUR OF THE DAY THE SIMULATION(STORM) BEGINS
*C        EQ.1 FOR MIDNIGHT THROUGH 1 AM PERIOD
*C        EQ.2 FOR 1 AM     THROUGH 2 AM PERIOD
*C          .       ....             ....
*C          .       ....             ....
*C
*C      KMIN:THE MINUTE OF THE HOUR THE SIMULATION(STORM) BEGINS
*C
*       READ(5,3000)KONTRL,KDAY,KHOUR,KMIN,IDATA
* 3000  FORMAT(I1,3(1X,I2),I5)
*****************************************************************
                                I
                                I
                                I
*****************************************************************
*       IF(KONTRL .LT. 1 .OR. KONTRL .GT. 4)GO TO 910
*****************************************************************
                                I
                                I
                                I
*****************************************************************
*       IF(KDAY .LT. 0 .OR. KDAY .GT. 7)GO TO 920
*****************************************************************
                                I
                                I
                                I
*****************************************************************
*       IF(KHOUR .LT. 1 .OR. KHOUR .GT. 24)GO TO 930
*****************************************************************
                                I
                                I
                                I
*****************************************************************
*       IF(KMIN .LT. 0 .OR. KMIN .GT. 60)GO TO 940
*****************************************************************
                                I
                                I
                                I
*****************************************************************
*  350  WRITE(6,4000)
* 4000  FORMAT(1H1,///5X,35HC O N T R O L   P A R A M E T E R S,/ )
*       WRITE(6,4010)KONTRL
* 4010  FORMAT(//5X,
*     &55HSIMULATION CONTROL CODE   . . . . . . . . . . . (KONTRL)=,I7 /5X,
*     &55H  EQ. 1, BOTH QUANTITY AND QUALITY OF COMBINED SYSTEM      /5X,
*     &55H  EQ. 2, BOTH QUANTITY AND QUALITY OF SEPERATE SYSTEM      /5X,
*     &55H  EQ. 3, ONLY QUANTITY OF COMBINED SYSTEM                  /5X,
*     &55H  EQ. 4, ONLY QUANTITY OF SEPERATE SYSTEM                     )
*       WRITE(6,4020) IDATA
* 4020  FORMAT(///5X,
*     &55HINPUT DATA DESCRIPTION PRINTOUT CODE  . . . . (IDATA )=I7/5X,
*     &55H  LE. 0, NO DETAILED DESCRIPTION OF INPUT DATA             /5X,
*     &55H  GT. 0, DETAILED DESCRIPTION PRINTOUT OF INPUT DATA          )
*****************************************************************
                                I
                                I
                                I
*****************************************************************
*       IF(IDATA .LE. 0)GO TO 310
*****************************************************************
```

```
                                                      I                                                             B    D    F    H    J    L    N
                                                      I                                                             B    D    F    H    J    L    N
                                                      I                                                             B    D    F    H    J    L    N
****************************************************************************************************                B    D    F    H    J    L    N
*       IF(KONTRL .NE. 1 .AND. KONTRL .NE. 3)GO TO 410                                               *......B....D....F....H....J..>V    N
****************************************************************************************************                B    D    F    H    J    L    N
                                                      I                                                             B    D    F    H    J    L    N
                                                      I                                                             B    D    F    H    J    L    N
                                                      I                                                             B    D    F    H    J    L    N
****************************************************************************************************                B    D    F    H    J    L    N
*       WRITE(6,4100)KDAY                                                                            *              B    D    F    H    J    L    N
* 4100 FORMAT(///5X,                                                                                 *              B    D    F    H    J    L    N
*     &55HDAY OF THE WEEK THE STORM BEGINS . . . . . . . (KDAY  )=,I7 /5X,*                                         B    D    F    H    J    L    N
*     &55H  EQ. 1, FOR SUNDAY                                                    /5X,*                              B    D    F    H    J    L    N
*     &55H  EQ. 2, FOR MONDAY                                                    /5X,*                              B    D    F    H    J    L    N
*     &55H       .          ..                                                   /5X,*                              B    D    F    H    J    L    N
*     &55H       .          ..                                          )            *                              B    D    F    H    J    L    N
*       IF(KDAY .EQ. 0)WRITE(6,4110)                                                 *                              B    D    F    H    J    L    N
* 4110 FORMAT(/7X,23HDEFAULT VALUE WILL BE 1                                        )*                              B    D    F    H    J    L    N
*       WRITE(6,4200)KHOUR                                                           *                              B    D    F    H    J    L    N
* 4200 FORMAT(/////5X,                                                               *                              B    D    F    H    J    L    N
*     &55HHOUR OF THE DAY THE STORM BEGINS . . . . . . . (KHOUR )=,I7 /5X,*                                         B    D    F    H    J    L    N
*     &55H  EQ. 1, FOR MIDNIGHT THROUGH 1 AM. PERIOD                             /5X,*                              B    D    F    H    J    L    N
*     &55H  EQ. 2, FOR 1 AM.     THROUGH 2 AM. PERIOD                            /5X,*                              B    D    F    H    J    L    N
*     &55H       .        .....              .....                               /5X,*                              B    D    F    H    J    L    N
*     &55H       .        .....              .....                      )            *                              B    D    F    H    J    L    N
*       IF(KHOUR .EQ. 0)WRITE(6,4110)                                                *                              B    D    F    H    J    L    N
*       WRITE(6,4300)KMIN                                                            *                              B    D    F    H    J    L    N
* 4300 FORMAT(//5X,                                                                  *                              B    D    F    H    J    L    N
*     &55HMINUTE OF THE HOUR THE STORM BEGINS . . . . . . (KMIN  )=,I7    )*                                        B    D    F    H    J    L    N
****************************************************************************************************                B    D    F    H    J    L    N
                                                      I                                                             B    D    F    H    J    L    N
                                                      O<............................................................B....D....F....H....J....O    N
                                                      I                                                             B    D    F    H    J         N
****************************************************************************************************                B    D    F    H    J         N
*  410 CONTINUE                                                                      *                              B    D    F    H    J         N
*C                                                                                   *                              B    D    F    H    J         N
*C      QUANTITY SIMULATION                                                          *                              B    D    F    H    J         N
*C                                                                                   *                              B    D    F    H    J         N
*       CALL QNTITY                                                                  *                              B    D    F    H    J         N
*C                                                                                   *                              B    D    F    H    J         N
*C      IF ONLY QUANTITY SIMULATION                                                  *                              B    D    F    H    J         N
*C                                                                                   *                              B    D    F    H    J         N
****************************************************************************************************                B    D    F    H    J         N
                                                      I                                                             B    D    F    H    J         N
```

```
                                                  I
                                                  I
                                                  I
                                                  I
******************************************************************
*      IF(KONTRL .GT. 2)GO TO 400                                *
******************************************************************
                                                  I
                                                  I
                                                  I
******************************************************************
*C                                                               *
*C     QUALITY SIMULATION                                        *
*C                                                               *
*      CALL QLTITY                                               *
******************************************************************
                                                  I
                                                  O<.............
                                                  I
******************************************************************
*  400 NJOB=NJOB+1                                               *
*C                                                               *
*C     NEXT CASE STUDY                                           *
*C                                                               *
******************************************************************
                                                  I
                                                  I
                                                  I
******************************************************************
*      GO TO 100                                                 *
******************************************************************
                                                  O<.............
                                                  I
******************************************************************
*  500 CONTINUE                                                  *
*C                                                               *
*C     JOB LOG                                                   *
*C                                                               *
*      WRITE(6,6000)NJOB                                         *
* 6000 FORMAT(/////,45X,39H***** M L S U R M   J O B   L O G *****,//45X,*
*     I15,14H JOBS EXECUTED)                                     *
******************************************************************
                                                  I
                                                  I
                                                  I
******************************************************************
*      RETURN                                                    *
******************************************************************
```

```
                                                                                 D    F    H                          N
                                                                                 D    F    H                          N
                                        0<.......................................D....0    H                          N
                                        I                                        D         H                          N
****************************************************************************     D         H                          N
*  910 WRITE(6,9100)KONTRL                                                 *     D         H                          N
* 9100 FORMAT(/////,6H ERROR,127(1H*)                              //6X,*        D         H                          N
*      &55HSIMULATION CONTROL CODE    . . . . . . . . . . (KONTRL)=,I3/ 6X,*     D         H                          N
*      &55HKONTRL MUST BE .GE. 1 .AND. .LE. 4                      //6X,*        D         H                          N
*      &55HEXECUTION STOP AT (XQTICN) SUBROUTINE              )          *       D         H                          N
****************************************************************************     D         H                          N
                                        I                                        D         H                          N
                                        I                                        D         H                          N
                                        I                                        D         H                          N
****************************************************************************     D         H                          N
*       GO TO 9999                                                         *......0  D    H                          N
****************************************************************************  B  D         H                          N
                                                                              B  D         H                          N
                                        0<....................................B..D.........H..........................0
                                        I                                     B  D         H
****************************************************************************  B  D         H
*  920 WRITE(6,9200)KDAY                                                   *  B  D         H
* 9200 FORMAT(/////,6H ERROR,127(1H*)                              //6X,*     B  D         H
*      &55HDAY OF THE WEEK THE STORM BEGINS  . . . . . . (KDAY   )=,I3/ 6X,*  B  D         H
*      &55HKDAY MUST BE .GE. 0 .AND. .LE. 7                        //6X,*     B  D         H
*      &55HEXECUTION STOP AT (XQTICN) SUBROUTINE              )          *    B  D         H
****************************************************************************  B  D         H
                                        I                                     B  D         H
                                        I                                     B  D         H
                                        I                                     B  D         H
****************************************************************************  B  D         H
*       GO TO 9999                                                         *.....>V  D     H
****************************************************************************  B  D         H
                                                                              B  D         H
                                        0<....................................B..D         H
                                        I                                     B            H
****************************************************************************  B            H
*  930 WRITE(6,9300)KHOUR                                                  *  B            H
* 9300 FORMAT(/////,6H ERROR,127(1H*)                              //6X,*     B            H
*      &55HHOUR OF THE DAY THE STORM BEGINS  . . . . . . (KHOUR )=,I3/ 6X,*   B            H
*      &55HKHOUR MUST BE .GE. 0 .AND. .LE. 24                      //6X,*     B            H
*      &55HEXECUTION STOP AT (XQTICN) SUBROUTINE              )          *    B            H
****************************************************************************  B            H
                                        I                                     B            H
                                        I                                     B            H
                                        I                                     B            H
****************************************************************************  B            H
*       GO TO 9999                                                         *.....>V        H
****************************************************************************  B            H
                                                                              B            H
```

```
                                                                              B           H
                                                                              B           H
                                   O<.........................................B...........O
                                   I                                          B
************************************************************************      B
*  940 WRITE(6,9400)KMIN                                               *      B
* 9400 FORMAT(/////,6H ERROR,127(1H*)                             //6X,*      B
*     &55HMINUTE OF THE HOUR THE STORM BEGINS . . . . . (KMIN  )=,I3/ 6X,*    B
*     &55HKMIN MUST BE .GE. 0 .AND. .LE. 60                       //6X,*      B
*     &55HEXECUTION STOP AT (XQTIEN) SUBROUTINE               )        *      B
************************************************************************      B
                                   I                                          B
                                   O<.........................................O
                                   I
************************************************************************
* 9999 CONTINUE                                                        *
*      CALL RMCARD                                                     *
************************************************************************
                                   I
                                   I
                                   I
************************************************************************
*      STOP                                                            *
************************************************************************


************************************************************************
*      END                                                             *
************************************************************************
```

```
                              (ENTRANCE)
                                  I
                                  I
**********************************************************************
*       SUBROUTINE QNTITY                                            *
*C                                                                   *
*C                                                                   *
*C   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *
*C   .                                                             . *
*C   .  P R O G R A M                                              . *
*C   .                                                             . *
*C   .       THE QUANTITY SIMULATION SUBROUTINE                    . *
*C   .                                                             . *
*C   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *
*C                                                                   *
*C                                                                   *
*       REAL*8 PNAME                                                 *
*       REAL S                                                       *
*       LOGICAL QNFLAG,QLFLAG                                        *
*       COMMON/BUF    / TITLE(20)                                    *
*       COMMON/LOGIC / QNFLAG,QLFLAG                                 *
*       COMMON/CONTRL/ DWFDCO(7),DWFHCO(24),                         *
*      &               DELTA,AINTER,AROC,KONTRL,KDAY,KHOUR,KMIN,     *
*      &               NN,NP,MAXTIM,NRAIN,MXRNIN,KALMS,NCHEX,NSUB    *
*       COMMON/LCONTR/ SSDCO(7),BODDCO(7),SSHCO(24),BODHCO(24),COLHCO(24),*
*      &               DRYDAY,CLFREQ,DWFDAY,NOPASS,NPOLL             *
*       COMMON/COMDWF/ CPI,CCCI,POPULA,ADWF,TOTA,TINA,TCA,TRHA,TRAA, *
*      &               TRLA,TRGGA,TPOA,SUMQPF,C2DWF,CF,CF2,SMTDWF,   *
*      &               TOTPOP,SUMSS,SUMBOD,KASL,NPF                  *
*       COMMON/NPOINT/ NR01,NR02,NR03,NR04,NR05,NR06,                *
*      &               NB10,NB01,NB02,NB03,NB04,NB05,NB06,NB07,NB08, *
*      &               NB09,NB10,NB11,NG01,NG02,NG03,NG04,NG05,NG06, *
*      &               NG07,NG08,                                    *
*      &               ND01,ND02,ND03,ND04,ND05,ND06,ND07,NQPF,      *
*      &               NS10,NS01,NS02,NS03,NS04,NS05,NS06,NS07,NS08, *
*      &               NS09,NS10,NS11,                               *
*      &               NQDV,NTOV,NCVD,NTGT,NSBH,                     *
*      &               NXTS,NBSF,NBGT,NTSW,NQFU,NXLD,NQSW            *
*       COMMON/LPOINT/ LPID,LKDD,LNSH,LNCH,LVCU,LCC1,LCC2,           *
*      &               LUSF,LCKB,LSAR,                               *
*      &               LPDW,LSSS,LBDS,LCLS,                          *
*      &               LTDD,LVOL,LHRD,LBOD,LBED,LBSS,                *
*      &               LPGV,LFIN,LFCD,LCPO,LBSP,LPRC,LOOP01          *
*       COMMON/CONST1/ SPG,BVAL                                      *
*       COMMON/CONST2/ DOLR(5),SSPOT(5),BODPOT(5),COLPOT(5),CODPOT(5),*
*      &               PNPOT(5),PO4POT(5)                            *
*       COMMON/CONST3/ PNAME(6),NALLOW                               *
*       COMMON/INTPO / JIN(21),VAR(21),FUN(21)                       *
*       COMMON/MXSIZE/ MSOS,LAST                                     *
*       COMMON S(1)                                                  *
*       DATA SNAME1,SNAME2/4HQNTI,4HTY                               *
*       QNFLAG=.TRUE.                                                *
*C                                                                   *
*C      QUANTITY SIMULATION CONTROL PARAMETERS                       *
*C                                                                   *
*       CALL INPUT                                                   *
*C                                                                   *
*C      ALLOCATION POINTERS FOR SUBCATCHMENT AND GUTTER DATA         *
*C                                                                   *
*C      NR01:NGAGE(NRAIN)                                            *
*C      NR02:INRAIN(NRAIN)                                           *
```

```
*C      NR03:DEPTH(NRAIN,MXRNIN)                                             *
*C      NR04:DURAT(NRAIN,MXRNIN)                                             *
*C      NR05:TIME(NRAIN,MXRNIN)                                              *
*C      NR06:INTEN(NRAIN,MXRNIN)                                             *
*C      NBID:IDSUBC(NN)                                                      *
*C      NB01:NHYET(NN)                                                       *
*C      NB02:NCOL(NN)                                                        *
*C      NB03:NSPRNT(NN)                                                      *
*C      NB04:AREA(NN)                                                        *
*C      NB05:XFRACT(NN)                                                      *
*C      NB06:OLENIP(NN)                                                      *
*C      NB07:SLOPIP(NN)                                                      *
*C      NB08:OMANIP(NN)                                                      *
*C      NB09:OLENPV(NN)                                                      *
*C      NB10:SLOPPV(NN)                                                      *
*C      NB11:OMANPV(NN)                                                      *
*C      NG01:NNOG(NN)                                                        *
*C      NG02:NGTYPE(NN)                                                      *
*C      NG03:GLENG(NN)                                                       *
*C      NG04:GSLOP(NN)                                                       *
*C      NG05:GROUGH(NN)                                                      *
*C      NG06:GGEOM1(NN)                                                      *
*C      NG07:GGEOM2(NN)                                                      *
*C      NG08:GGEOM3(NN)                                                      *
*C                                                                           *
*C                                                                           *
*C                                                                           *
*       NR01=1                                                               *
*       NR02=NR01+NRAIN                                                      *
*       NR03=NR02+NRAIN                                                      *
*       NR04=NR03+NRAIN*MXRNIN                                               *
*       NR05=NR04+NRAIN*MXRNIN                                               *
*       NR06=NR05+NRAIN*MXRNIN                                               *
*       NBID=NR06+NRAIN*MXRNIN                                               *
*       NB01=NBID+NN                                                         *
*       NB02=NB01+NN                                                         *
*       NB03=NB02+NN                                                         *
*       NB04=NB03+NN                                                         *
*       NB05=NB04+NN                                                         *
*       NB06=NB05+NN                                                         *
*       NB07=NB06+NN                                                         *
*       NB08=NB07+NN                                                         *
*       NB09=NB08+NN                                                         *
*       NB10=NB09+NN                                                         *
*       NB11=NB10+NN                                                         *
*       NG01=NB11+NN                                                         *
*       NG02=NG01+NN                                                         *
*       NG03=NG02+NN                                                         *
*       NG04=NG03+NN                                                         *
*       NG05=NG04+NN                                                         *
*       NG06=NG05+NN                                                         *
*       NG07=NG06+NN                                                         *
*       NG08=NG07+NN                                                         *
*       LAST=NG08+NN                                                         *
*       NLAST=LAST-1                                                         *
*       CALL SIZE(NLAST,4HNG08,4H    ,SNAME1,SNAME2)                         *
*C                                                                           *
*C      QUANTITY DATA INPUT                                                  *
*C                                                                           *
*       CALL QNDATA(                                                         *
*      &S(NR01),S(NR02),S(NR03),S(NR04),S(NR05),S(NR06),S(NB01),             *
```

```
*        &S(NB02),S(NB03),S(NB04),S(NB05),S(NB06),S(NB07),S(NB08),              *
*        &S(NB09),S(NB10),S(NB11),S(NG01),S(NG02),S(NG03),S(NG04),              *
*        &S(NG05),S(NG06),S(NG07),S(NG08),S(NBID)                              )*
*C                                                                              *
*C        NQOV:QOVEND(NN,MAXTIM)                                                *
*C        NTOV:MXTOVR(NN)                                                       *
*C        NCVO:ICONVR(NN)                                                       *
*C        NTGT:TIMGUT(NN)                                                       *
*C        NSBH:SUBHYD(MAXTIM)                                                   *
*C                                                                              *
*         NQOV=LAST                                                             *
*         NTOV=NQOV+NN*MAXTIM                                                   *
*         NCVO=NTOV+NN                                                          *
*         NTGT=NCVO+NN                                                          *
*         NSBH=NTGT+NN                                                          *
*         LAST=NSBH+MAXTIM                                                      *
*         NLAST=LAST-1                                                          *
*         CALL SIZE(NLAST,4HNSBH,4H    ,SNAME1,SNAME2)                          *
*         CALL INITAL(NN,S(NCVO),S(NTGT))                                       *
*         CALL QNSUBF(                                                          *
*        &S(NR01),S(NR02),S(NR04),S(NR05),S(NR06),S(NB01),S(NB04),              *
*        &S(NB05),S(NB06),S(NB07),S(NB08),S(NB09),S(NB10),S(NB11),              *
*        &S(NQOV),S(NTOV),S(NCVO),S(NTGT),S(NSBH),S(NBID)                      )*
*C                                                                              *
*C                                                                              *
*C                                                                              *
*C                                                                              *
*C                                                                              *
*C                                                                              *
*C                                                                              *
*C                                                                              *
*C        ALLOCATION POINTERS                                                   *
*C                                                                              *
*C        NXTS:MXTSEW(NP)                                                       *
*C        NBSF:BSFLOW(NP)                                                       *
*C        NBGT:BEGINT(NP)                                                       *
*C        NTSW:TIMSEW(NP)                                                       *
*C        NQFU:QFULL(NP)                                                        *
*C        NXED:EXCEED(NP)                                                       *
*C        NQSW:QSEWER(NP,MAXTIM)                                                *
*C                                                                              *
*         NXTS=LAST                                                             *
*         NBSF=NXTS+NP                                                          *
*         NBGT=NBSF+NP                                                          *
*         NTSW=NBGT+NP                                                          *
*         NQFU=NTSW+NP                                                          *
*         NXED=NQFU+NP                                                          *
*         NQSW=NXED+NP                                                          *
*         LAST=NQSW+NP*MAXTIM                                                   *
*         NLAST=LAST-1                                                          *
*         CALL SIZE(NLAST,4HNQSW,4H    ,SNAME1,SNAME2)                          *
*         CALL GNROUT(                                                          *
*        &S(NQOV),S(NTOV),S(NB02),S(NS01),S(NS02),S(NS04),S(NS05),              *
*        &S(NS06),S(NS07),S(NS08),S(NS09),S(NXTS),S(NBSF),S(NBGT),              *
*        &S(NTSW),S(NQFU),S(NXED),S(NQSW),S(NSID)                              )*
*         IF(KONTRL .LE. 2)RETURN                                               *
*         CALL AOUTPU(                                                          *
*        &S(NB01),S(NB02),S(NB03),S(NB04),S(NB05),S(NB06),S(NB07),              *
*        &S(NB08),S(NB09),S(NB10),S(NB11),S(NQOV),S(NTOV),S(NCVO),              *
*        &S(NS01),S(NS02),S(NS03),S(NS04),S(NS05),S(NS06),S(NS07),              *
*        &S(NS08),S(NS09),S(NS10),S(NS11),S(NXTS),S(NBGT),S(NTSW),              *
```

```
*      &S(NQFU),S(NXED),S(NGSW),S(NBID),S(NSID)                              )*
**********************************************************************************
                                   I
                                   I
                                   I
**********************************************************************************
*       RETURN                                                                   *
**********************************************************************************

**********************************************************************************
*       END                                                                      *
**********************************************************************************
```

(ENTRANCE)

```
*       SUBROUTINE QLTITY
*C
*C
*C   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
*C   .
*C   .   P R O G R A M
*C   .
*C   .        THE QUALITY SIMULATION SUBROUTINE
*C   .
*C   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
*C
*C
*       REAL*8 PNAME
*       REAL S
*       LOGICAL QNFLAG,GLFLAG
*       COMMON/BUF    / TITLE(20)
*       COMMON/LOGIC / QNFLAG,GLFLAG
*       COMMON/CONTRL/ DWFDCO(7),DWFHCO(24),
*      &               DELTA,AINTER,AROC,KONTRL,KDAY,KHOUR,KMIN,
*      &               NN,NP,MAXTIM,NRAIN,MXRNIN,KALMS,NCHEX,NSUB
*       COMMON/LCONTR/ SSDCO(7),BODDCO(7),SSHCO(24),BODHCO(24),COLHCO(24),
*      &               DRYDAY,CLFREQ,DWFDAY,NOPASS,NPOLL
*       COMMON/COMDWF/ CPI,CCCI,POPULA,ADWF,TCTA,TINA,TCA,TRHA,TRAA,
*      &               TRLA,TRGGA,TPGA,SUMQPF,C2DWF,CF,CF2,SMTDWF,
*      &               TOTPOP,SUMSS,SUMBOD,KASE,NPF
*       COMMON/NPOINT/ NR01,NR02,NR03,NR04,NR05,NR06,
*      &               NB10,NB01,NB02,NB03,NB04,NB05,NB06,NB07,NB08,
*      &               NB09,NB11,NB11,NG01,NG02,NG03,NG04,NG05,NG06,
*      &               NG07,NG08,
*      &               ND01,ND02,ND03,ND04,ND05,ND06,ND07,NQPF,
*      &               NS10,NS01,NS02,NS03,NS04,NS05,NS06,NS07,NS08,
*      &               NS09,NS11,NS11,
*      &               NGOV,NTOV,NCVO,NTST,NSBH,
*      &               NXTS,NBSF,NAGT,NTSW,NOFU,NXFD,NGSW
*       COMMON/LPOINT/ LP10,LK00,LNSB,LNCB,LVCO,LCB1,LCB2,
*      &               LOSF,LCRB,LSAR,
*      &               LPDW,LSSS,LBOS,LCLS,
*      &               LTOD,LVOL,LHRD,LTDD,LBED,LBSS,
*      &               LPOV,LFIN,LFED,LCFC,LBSP,LPRC,LOOP01
*       COMMON/CONST1/ SPG,EVAL
*       COMMON/CONST2/ DDLR(5),SSPOT(5),BODPOT(5),COLPOT(5),CODPUT(5),
*      &               PNPOT(5),PO4POT(5)
*       COMMON/CONST3/ PNAME(6),NALLOW
*       COMMON/INTPO / QIN(21),VAH(21),FUN(21)
*       COMMON/MXSIZE/ MSOS,LAST
*       COMMON S(1)
*       DATA SNAME1,SNAME2/4HQLTI,4HTY
*C
*C      SET THE QUALITY CONTROL FLAG
*C
*       QLFLAG=.TRUE.
*C
*C      READ IN QUALITY SIMULATION CONTROL PARAMETERS
*C
*       CALL INPUT
*C
*C      ALLOCATION POINTERS
```

```
*C                                                                          *
*C      LNSB:NNOSUB(NN)   ** SHARE LOCATIONS WITH N001 IF KONTRL=1          *
*C      LNCB:NNCB(NN)                                                       *
*C      LVCB:VOLCB(NN)                                                      *
*C      LCB1:BODCB(NN)                                                      *
*C      LCB2:CUDCB(NN)                                                      *
*C      LUSE:LOCLAS(NN,NSUB)                                                *
*C      LCRB:CURBL(NN,NSUB)                                                 *
*C      LSAR:ASUBA(NN,NSUB)   ** SHARE LOCATIONS WITH N004 IF KONTRL=1      *
*C                                                                          *
*****************************************************************************
                                     I
                                     I
                                     I
*****************************************************************************
*       IF(KONTRL .EQ. 1)GO TO 100                                          *......O
*****************************************************************************      B
                                     I                                             B
                                     I                                             B
                                     I                                             B
*****************************************************************************      B
*       LNSB=LAST                                                           *      B
*       LNCB=LNSB+NN                                                        *      B
*****************************************************************************      B
                                     I                                             B
                                     I                                             B
                                     I                                             B
*****************************************************************************      B
*       GO TO 200                                                           *......B.......O
*****************************************************************************      B       F
                                                                                   B       F
                                     O<............................................O       F
                                     I                                                     F
*****************************************************************************              F
*   100 LNSB=N001                                                           *              F
*       LNCB=LAST                                                           *              F
*****************************************************************************              F
                                     I                                                     F
                                     O<....................................................O
                                     I
*****************************************************************************
*   200 LVCB=LNCB+NN                                                        *
*       LCB1=LVCB+NN                                                        *
*       LCB2=LCB1+NN                                                        *
*       LUSE=LCB2+NN                                                        *
*       LCRB=LUSE+NN*NSUB                                                   *
*       LSAR=LCRB+NN*NSUB                                                   *
*****************************************************************************
                                     I
```

```
                                              I
                                              I
                                              I
                                              I
*************************************************************************
*       IF(KONTRL .EQ. 1)GO TO 300                                      *.......O
*************************************************************************       B
                                              I                                 B
                                              I                                 B
                                              I                                 B
*************************************************************************       B
*       LAST=LSAR+NN*NSUB                                               *       B
*       NLAST=LAST-1                                                    *       B
*       CALL SIZE(NLAST,4HLSAR,4H     ,SNAME1,SNAME2)                   *       B
*************************************************************************       B
                                              I                                 B
                                              I                                 B
                                              I                                 B
*************************************************************************       B
*       GO TO 400                                                       *.......B........O
*************************************************************************       B        F
                                                                                B        F
                                              O<................................O        F
                                              I                                          F
*************************************************************************                F
*  300 LAST=LSAR                                                        *                F
*       LSAR=ND04                                                       *                F
*       NLAST=LAST-1                                                    *                F
*       CALL SIZE(NLAST,4HLCRB,4H     ,SNAME1,SNAME2)                   *                F
*C                                                                      *                F
*C      QUALITY DATA INPUT                                              *                F
*C                                                                      *                F
*************************************************************************                F
                                              I                                          F
                                              O<.........................................O
                                              I
*************************************************************************
*  400 CALL QLDATA(                                                     *
*      &S(LNSB),S(LNCB),S(LVCE),S(LCB1),S(LCB2),S(LUSE),S(LCRB),        *
*      &S(LSAR),S(NBID),S(NB04)                                        )*
*C                                                                      *
*C      ALLOCATION POINTERS                                             *
*C                                                                      *
*C      LTDD:TOTDD(NN,NSUB)                                             *
*C                                                                      *
*       LTDD=LAST                                                       *
*       LAST=LTDD+NN*NSUB                                               *
*       NLAST=LAST-1                                                    *
*       CALL SIZE(NLAST,4HLTDD,4H     ,SNAME1,SNAME2)                   *
*C                                                                      *
*C      DUST & DIRT ACCUMULATION PRIOR TO STORM                         *
*C                                                                      *
*       CALL DDLOAD(S(NBID),S(LNSE),S(LUSE),S(LCRB),S(LTDD)            )*
*C                                                                      *
*C      ALLOCATION POINTERS                                             *
*C                                                                      *
*C      LVOL:VOL(MAXTIM)                                                *
*C      LHRD:HRAD(MAXTIM)   ** FOR SS ONLY, ADDRESS WILL BE ASSIGNED IN *
*C                              SORTSS SUBROUTINE                       *
*C                                                                      *
```

```
*       LVOL=LAST                                                        *
*       LAST=LVOL+MAXTIM                                                 *
*       NLAST=LAST-1                                                     *
*       CALL SIZE(NLAST,4HLVOL,4H    ,SNAME1,SNAME2)                     *
*       CALL SORTSS(S(LPID),KSS                                         )*
*C                                                                       *
*C      STORAGE LOCATIONS S(NSBH) WILL BE OVERLAPPED BY                  *
*C         QUPSTR(MAXTIM) IN VOLSAV SUBROUTINE                           *
*C                                                                       *
*       CALL VOLSAV(                                                     *
*      &S(NSID),S(NS01),S(NS04),S(NS05),S(NS06),S(NS07),S(NS08),         *
*      &S(NS09),S(NQFU),S(NQSW),S(NSBH),S(LVOL),S(LHRD),KSS             )*
*C                                                                       *
*C      IF SS IS NOT TO BE SIMULATED                                     *
*C                                                                       *
**************************************************************************
                                    I
                                    I
                                    I
**************************************************************************
*       IF(KSS .LE. 1)GO TO 500                                          *.......B
**************************************************************************       B
                                    I                                            B
                                    I                                            B
                                    I                                            B
**************************************************************************       B
*C                                                                       *       B
*C      IF SS IS TO BE SIMULATED                                         *       B
*C                                                                       *       B
*C      ALLOCATION POINTERS                                              *       B
*C                                                                       *       B
*C      LBDO:BEDO(NP)                                                    *       B
*C      LBED:SCOUR(NP)                                                   *       B
*C      LBSS:BSSPLO(NP)   ** WILL BE DELETED AFTER PROCESSING            *       B
*C                                                                       *       B
*       LBDO=LAST                                                        *       B
*       LBED=LBDO+NP                                                     *       B
*       LBSS=LBED+NP                                                     *       B
*       LAST=LBSS+NP                                                     *       B
*       NLAST=LAST-1                                                     *       B
*       CALL SIZE(NLAST,4HLBSS,4H    ,SNAME1,SNAME2)                     *       B
*C                                                                       *       B
*C      INITIAL BED LOAD OF SOLIDS PRIOR TO STORM DUE TO DWF             *       B
*C                                                                       *       B
*       CALL DWLOAD(                                                     *       B
*      &S(NSID),S(NB02),S(NS01),S(NS02),S(NS04),S(NS05),S(NS06),         *       B
*      &S(NS07),S(NS08),S(NS09),S(NBSF),S(NQFU),S(LPDW),S(LBDO),         *       B
*      &S(LBED),S(LBSS)                                                 )*       B
*C                                                                       *       B
*C      DELETE BSSPLO(NP)                                                *       B
*C                                                                       *       B
*       LAST=LBSS                                                        *       B
**************************************************************************       B
                                    I                                            B
```

```
                                                    I                                                  B
                                                    I                                                  B
                                                    I                                                  B
                                                    I                                                  B
            ************************************************************************                   B
A...........*       DO 450 LDELET=LAST,NLAST                                           *               B
A           ************************************************************************                   B
A                                                   I                                                  B
A                                                   I                                                  B
A                                                   I                                                  B
A           ************************************************************************                   B
A           *       S(LDELET)=0.0                                                      *               B
A           ************************************************************************                   B
A                                                   I                                                  B
A                                                   I                                                  B
A                                                   I                                                  B
A           ************************************************************************                   B
............*   450 CONTINUE                                                           *               B
            ************************************************************************                   B
                                                    I                                                  B
                                                    I                                                  B
                                                    I                                                  B
            ************************************************************************                   B
            *C                                                                         *               B
            *C      QUALITY SIMULATIONS LOOP ON EACH QUALITY CONSTITUENT               *               B
            *C                                                                         *               B
            ************************************************************************                   B
                                                    I                                                  B
                                                    O<.................................................O
                                                    I
            ************************************************************************
            *   500 CONTINUE                                                           *
            *       CALL QLLOOP(S(LPID)                                               )*
            ************************************************************************
                                                    I
                                                    I
                                                    I
            ************************************************************************
            *       RETURN                                                             *
            ************************************************************************


            ************************************************************************
            *       END                                                                *
            ************************************************************************
```